ENGINEERING WONDERS OF THE WORLD

EDITED BY ARCHIBALD WILLIAMS

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OF THE WORLD

VOLUME III.

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CONTENTS

OF THE THIRD VOLUME

MECHANICAL FLIGHT AND AERIAL NAVIGATION 1

THE THEORY AND PRINCIPLES OF THE AEROPLANE 5

FLYING MACHINES OF TO-DAY 15

AERONAUTICAL ENGINES 29

THE CONSTRUCTION OF AEROPLANES AND AERIAL PROPELLERS . . 39

DIRIGIBLE BALLOONS 45

HARBOUR CONSTRUCTION 65

THE TRANS-SIBERIAN RAILWAY. By T. FLETCHER FULLARD, M.A. . . . 81

THE WATER SUPPLY OF NEW YORK CITY. By JOHN GEORGE LEIGH . . . 97

THE COLORADO RIVER CLOSURE 113

SOME EXTRAORDINARY SHIPBUILDING FEATS. By ALBERT G. HOOD . . 122

THE CONSTRUCTION OF THE FIRST AMERICAN TRANS-CONTINENTAL RAILROAD. By G. L. FOWLER 129

THE GREAT TUNNELS THROUGH THE ALPS 148

TRANSPORTATION CANALS OF THE UNITED STATES. By I. M. PEACOCK . . 163

GREAT BRITISH DAMS AND AQUEDUCTS. By the EDITOR 177

HOW LONDON GETS ITS WATER. By the EDITOR 193

THE WONDERFUL DRAINAGE SYSTEM OF LONDON. By the EDITOR . . 209

THE ELECTRIC POWER STATIONS OF LONDON. By E. LANCASTER BURNE, A.M.Inst.C.E. 226

THE GREAT IRRIGATION WORKS OF INDIA. By an INDIAN IRRIGATION ENGINEER . 232

BUILDING THE STATUE OF LIBERTY 250

REMARKABLE MACHINERY USED IN THE MANUFACTURE OF IRON AND STEEL. By FRED. G. SMITH 257

THE KINLOCHLEVEN WORKS OF THE BRITISH ALUMINIUM COMPANY . 272

THE ARCH BRIDGES OF NIAGARA FALLS 278

AGRICULTURAL ENGINEERING 288

TWO REMARKABLE ALPINE MOUNTAIN RAILWAYS 301

GREAT UNDERPINNING ACHIEVEMENTS. By W. T. PERKINS 312

THE DEVELOPMENT OF THE RACING MOTOR CAR 321

ARTESIAN WELLS, AND HOW THEY ARE BORED 335

THE BERGEN-KRISTIANIA RAILWAY 347

MODERN CABLES AND CABLE LAYING 357

MODERN DESTRUCTORS 377

THE COOLGARDIE AQUEDUCT 379

LIST OF COLOURED PLATES

IN THIS VOLUME

THE FIRST CROSS-CHANNEL FLIGHT	*To face Title-page.*
HARBOUR CONSTRUCTION—LOWERING A HUGE CONCRETE BLOCK	*To face page* 65
RAILROADMEN REPELLING AN ATTACK BY INDIANS	129
THE TOWER BRIDGE	193
A BESSEMER CONVERTER	257
A MOTOR RACE ON THE BROOKLANDS TRACK	321

THE FIRST CROSS-CHANNEL FLIGHT.

MECHANICAL FLIGHT AND AERIAL NAVIGATION.

INTRODUCTION.

As the beginning of last century witnessed the development of steam locomotion by land and sea, and its last decade the rise of the gas-driven automobile, so are the first years of the twentieth century witnessing the growth of a means of transit which holds out greater possibilities than any of its predecessors. There is no need to review the many abortive strivings of man to emulate the way of a bird in the air—attempts which were doomed to failure because they ran far ahead of the mechanical science of the time. In human progress there has been, and always must be, an ordered sequence. The locomotive was an impossibility while tools were crude and the means of making rails in bulk not yet available. The growth of the petroleum industry, the invention of the pneumatic tyre and of the internal combustion engine, and the existence of good roads, prepared the way for the motor car. And now we seem to have reached a period when, thanks to mechanical skill and scientific knowledge, the solution of the problems of aerial navigation cannot be delayed much longer. Though critics may scoff, facts are facts; and among the facts with which they have to reckon are that men *have* travelled hundreds of miles in dirigible balloons, and that men *have* flown on self-lifting machines for long distances at high speeds.

Success seems to have come quite suddenly. In 1852, Henry Giffard devised an airship that propelled itself at a low velocity; in 1884, Renard and Krebs produced one that proved considerably more successful; in 1900, Count Zeppelin first moved a dirigible with the aid of a petrol engine; in 1902, Santos Dumont won the Deutsch Prize with a short flight round the Eiffel Tower. These achievements sum up the progress made till seven years ago. To-day dirigible balloons are numerous; flying machines that *can* fly are to be counted by the score, and their number increases every week.

We must not forget, however, that the feats recently accomplished are the outcome of a great amount of experiment in the laboratory and in the open air. There has been little of what may be called accidental discovery in the story of the aeroplane. Slowly and systematically, with the aid of a multitude of models, the laws of the air have been explored, the problems of maintaining stability partly solved. If progress has been, on the whole, much slower than in the case of the steam locomotive, the steamship, and the electric and petrol-driven vehicle, it is due mainly to the characteristic difficulties of aerial navigation, the main one being that the failure of any man-carrying apparatus is attended by the most serious consequences, financial and physical. This meant a cautious advance into the fascinating field of aeronautics. A lot of work was done without achieving results such as would appeal to the popular imagination. Experimenters were regarded as fools, bent on breaking their necks. Arguments were marshalled to show that man was not intended to fly, and that therefore he should not endeavour to do so. It might have been maintained with equal fairness that man was not designed to travel on land at a hundred miles an hour, or on the sea at almost half that speed. The prejudice which overlooked these counter-arguments was based in no small degree upon an ignorance about or misconception of the physical qualities of the atmosphere. Though at rest, the air seems to have no substance; the hurricane—air moving at high velocity—makes playthings of solid structures. It shows a curious anomaly of thought that, while the dirigible balloon was regarded as foredoomed to failure as being unable to overcome air resistance, the flying machine should have been derided on the grounds that mere air would not serve for its support. The fundamental fact that air will give support to any mass if that mass be provided with suitable surfaces and be propelled at a sufficiently high speed is now, however, more generally recognized.

Though veritable engineering wonders, the airship and the flying machine are still in their infancy, so young that we cannot yet see clearly what form they are likely to take as they develop. Will the final victory rest with the dirigible balloon or with the heavier-than-air self-lifting and self-supporting machine? Or will there be uses found for both types of air craft? It is impossible to say.

The attitude which scouts the idea of aviation becoming more than a sport for the wealthy few seems hardly worthy of serious consideration. The advantages of being able to travel through the air, upborne by a medium which requires not a farthing's-worth of expenditure in repairs, and which is practically illimitable, are too obvious to need setting forth. The motor car has come into general use largely because of its capacity to save time in "cross-country" journeys, through districts not served by the railway. But even the car has to keep to the beaten track; to cross a river at one or other of a few points—often many miles apart—at which bridges have been built; to traverse mountain ranges where the engineers have made the roads. Long detours are, in many circumstances, unavoidable. The aeroplane and "dirigible" know no such limitations. Given the capacity to keep moving in the direction desired, there will be nothing to hinder them getting from any one place to any other.

What effects the new locomotion will have on society it is indeed difficult to foresee. Pessimists, directing their attention mainly to the combative instincts of mankind, croak

of aerial invasion and warfare in the clouds. The military side of aerial navigation has been, we venture to think, too widely emphasized. The locomotive has played a most important part in modern warfare, yet its mission has been mainly peaceful. Similarly, though the airship, like the submarine boat in another element, will be employed in war time on account of the moral effect produced by its possible presence, it will justify itself far more fully as a means of maintaining communication in many parts of the world whither roads and railway have not yet penetrated. Consider what an aerial postal service would mean to people living on the outskirts of civilization, in districts where pioneers are at present painfully feeling their way.

In the following chapters we are concerned, not with questions of the future, but with the past and present progress of aeronautics. We shall review the principles and problems of mechanical flight, and give attention to the most successful aeroplanes of to-day. The aeronautical engine, upon the development of which has depended so largely that of human flight, is treated in a separate article. The second main section is devoted to the airship or dirigible balloon.

Things are moving so fast, metaphorically as well as literally, in the field of aeronautics that we cannot hope to keep here quite abreast of the latest developments. Even while these articles pass through the press fresh triumphs will doubtless be won. The letterpress and illustrations will, however, have a value, even where they do not refer to principles rather than applications, as embodying a record of the early chapters in the history of the most fascinating, as it is the most recent, of engineering wonders.

A WRIGHT BIPLANE IN FLIGHT. *(Photo, Illustrations Bureau.)*

THE THEORY AND PRINCIPLES OF THE AEROPLANE.

THE physical laws governing the successful operation of an aeroplane are at the present time still being explored. Much valuable research work has been done by Lilienthal, Chanute, Maxim, Phillips, Lanchester, Langley, the Wrights, and others; and conclusions, capable of experimental proof, have been arrived at, so that human flight has moved from the position of mere aspiration into the region of accomplished fact. A great deal remains to be done, however, before man will rival the birds in this latest form of locomotion.

The scientific literature dealing with aerostatics is as yet comparatively scanty, and of a nature which may well scare the unscientific reader. It is our desire to avoid here tiresome technicalities, formulæ, and equations, and to present, in as simple a form as possible, the physical facts and problems with which experimenters have to deal.

Most of us have handled the toy kite, a very simple apparatus which is subservient to essentially the same laws as is the aeroplane.

The Kite.

When a kite is launched in a wind sufficiently strong to lift it at all, it speedily rises to a certain elevation, at which it remains so long as the velocity of the wind does not change. The steadiness of the kite implies an equilibrium of the forces acting upon it. These forces, as shown in Fig. 1, are: G, gravity, which remains practically unaltered under all conditions; W, the pressure of wind, acting perpendicularly to the oblique surface of the kite; and P, the pull of the string.

The force W may be resolved into two other forces. One of these, known as *drift*, tends to move the kite horizontally in the direction of the wind; the other, called *lift*, to raise the kite vertically in opposition to gravity. In practice, if not in theory, the drift is augmented by the direct resistance offered by edges, excrescences, and roughnesses of the kite.

If the wind sinks, the kite sinks also, increasing its angle with the horizontal. This causes it to capture and force downwards more

and more air until a state of equilibrium is again attained. We must observe, however, that this increase of angle means also a great increase in drift proportionately to lift. If the descent of the kite had been caused, not by decrease in wind velocity, but by the addition of weight to the kite, the increase in the pull on the string would have been very noticeable.

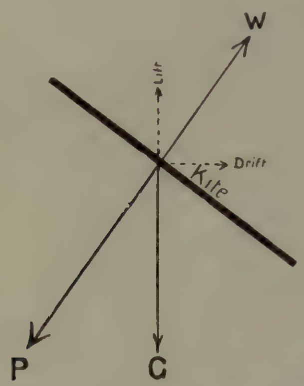


Fig. 1.—DIAGRAM TO SHOW THE FORCES ACTING ON A KITE.

It is the aim of the kite-maker as well as of the aeroplane builder to design surfaces which shall use the wind pressure most efficiently—that is, extract a maximum of lifting force, and be subject to a minimum of drift.

If the string of a kite breaks, the equilibrium of forces is destroyed; drift and gravity take command, and the kite either tumbles or glides to earth backwards. If it were possible to attach to the kite at the moment of rupture a weightless engine and propeller, exerting a horizontal windward push equal to the drift, the kite would remain stationary.

Again, were the wind to drop suddenly, and the engine to give the kite a forward velocity equal to that of the wind, the kite would move forward—assuming that it were able to maintain its stability—and be a true aeroplane or self-supporting heavier-than-air apparatus. Under usual conditions a kite is not strictly self-supporting, in that it depends on the resistance of a string anchored to a fixed point.

Lilienthal, the great German experimenter, Octave Chanute, the brothers Wright, and other seekers after aerostatical knowledge, made use of man-bearing "gliders," either free or anchored, of large area, as well as of laboratory tests on surfaces of various forms, from which was derived the preliminary knowledge necessary to the construction of mechanical self-propelled and self-sustaining machines. Without going into wearisome details, it may be stated that the shape and the arrangement of surfaces to give the greatest lifting power and stability were the chief objects of their search.

Gliders.

It was proved conclusively that (*a*) a true plane had not, area for area, so great a sustaining power as a slightly curved surface, convex on the upper side. Horatio Phillips, and subsequently Maxim, demonstrated by elaborate tests that (*b*) an aeroplane (we here apply the term to a sustaining surface, not to a machine) with the upper surface more curved than the lower, and inclining downwards in front so as to give a "negative entering angle" (see Fig. 2), was most efficient.

Shape of Supporting Surfaces.

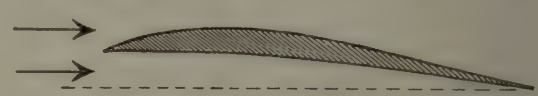


Fig. 2.—SECTION OF A DECK WHICH GIVES GOOD LIFTING POWER.
The arrows indicate the direction of the wind.

Tests showed that (*c*) depth fore and aft was not so important as length of transverse entering edge; that, in fact, a number of narrow aeroplanes, arranged one over the other, Venetian blind fashion, were much more effective than a single aeroplane of equal length and of a breadth totalling that of the narrow aeroplanes. It has been established that (*d*) in the case of well-made aeroplanes the lift increases, within certain limits, in direct proportion to the angle of inclination or incidence: thus, a plane making an angle of 10° with the horizontal has twice the lift of one inclined at 5° to the horizontal. Also that (*e*) the drift

varies, within certain limits, relatively to the lift with the angle of inclination: thus, an aeroplane set at an angle of 1 in 12 (that is, having the forward edge 1 inch higher than the rear edge for every foot of width) develops twelve times as much lift as drift. Also that (*f*) the lift increases as the *square* of the velocity of motion relatively to the air: therefore the

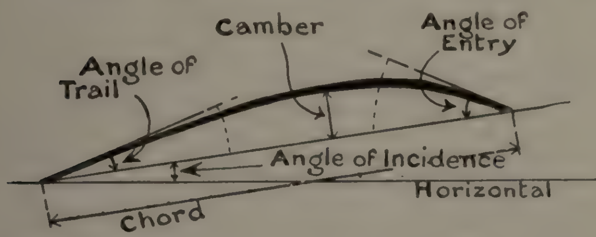


Fig 3.—DIAGRAM TO EXPLAIN TERMS "ANGLE OF INCIDENCE," "ANGLE OF ENTRY," "CAMBER," ETC.

higher the speed, the smaller the angle of the plane needed to sustain a given weight, and the greater the lifting effect in proportion to the power employed. This fact is due to the inertia of the air, and has its analogy in the fact that a skater travelling fast will be supported by ice that would not bear him at rest.

The cause of the great lifting power of a curved aeroplane with a downward-pointing front edge is not yet clearly understood.

Air Action.

Phillips advanced the theory that the upward push given to the air by the front edge creates a partial vacuum over the upper rear portion of the aeroplane. Maxim, on the other hand, has recorded his opinion that the air follows the upper curve and joins that passing along the underneath surface at the trailing edge, giving a resultant upward push. Whatever the correct explanation may be, the curved section is used generally, the ribs in some cases being tapered and covered on both sides, so as to make the curvature more pronounced on the top than on the bottom; in others, covered on the lower side only. There seems to be a lack of standardization in this respect at present.

Disposition of Planes.

As the lifting power of a flying machine increases, other things being equal, with its bearing surfaces, and is augmented by increasing the length of forward edge of these surfaces, as wide a spread as possible is, in this respect, a desideratum. The spread must, however, be limited to convenient dimensions. Hence one section of experimenters have adopted the *biplane*, with two "decks" set one above the other at a distance apart at least equal to the width of the decks, and a few have tried the *triplane* and *multiplane*. Blériot, Latham, and others have chosen the alternative of the *monoplane*, having a single deck subdivided into two wings, one on each side of a central "body." From the constructional point of view the biplane has the advantage of admitting a girder-like form of cross bracing between the two decks, and enabling the propeller or propellers to be mounted conveniently behind the decks, where, by virtue of acting on air already disturbed, they prove more efficient than the monoplane's tractor screw, which bites air previously undisturbed, and drives it back on to the body it is moving. Yet the performances of the monoplane have been so satisfactory as regards speed that one is driven to the conclusion that as yet it is too early to dogmatize on the respective merits of the two types.

Aspect Ratio.

We may digress here for a moment to introduce and explain the term "aspect ratio," now commonly used in describing the shape of a deck. An aspect ratio of 6 to 1, for example, implies that the greatest length from end to end is six times the greatest depth from the front to the rear edge.

From what has been said already, it will be deduced that the ability of a flying machine to keep in the air depends on (1) the design of the supporting surfaces; (2) the area of the supporting surfaces; (3) the inclination of the supporting surfaces; (4) the speed of

travel, which in turn is dependent on the motive force. When travelling horizontally the machine is practically constantly climbing a slope equal to that of the natural gliding angle of descent which it takes to earth when the engines are stopped. So that in effect the power required to sustain it must be equivalent to the extra power (above that developed on the level) needed to drive a motor car of equal weight at an

The Design of a Flying Machine.

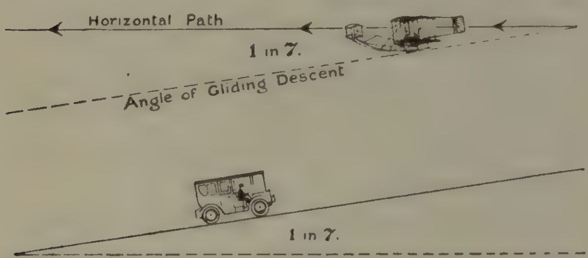


Fig. 4.

An aeroplane travelling horizontally has, weight for weight, to exert as much force to support itself as is required to propel a motor car up an incline having a gradient equal to the gliding angle of the aeroplane.

equal speed up an incline equal to the gliding angle of the aeroplane, and, in addition, to overcome the air resistance and skin friction of all parts of the machine. The first factor, the aerodynamic resistance, is decreased relatively to the lift by higher speed, since, as we have seen already, the lift increases with the speed; the second factor, head resistance, increases in the same ratio, as the square of the velocity. Hence one factor tends to counterbalance the other. It follows from this that for any one machine there is a certain speed at which it will support itself and travel from one point to another most economically—that is, with the least expenditure of force. To improve the speed without increasing the power or altering the weight, the head resistance must be diminished, or the design of the decks improved and the inclination reduced. Should the designer elect rather to decrease the supporting area without increasing engine power, he would be compelled to increase also the inclination of the decks—and with it the "drift"—which would tend to diminish speed—a very undesirable alternative.

An aeroplane must travel at a certain speed to support itself at all. To enable it to rise, the power must be increased. Merely to point an elevating rudder upwards will not suffice, as the increase of inclination will increase the "drift" of the supporting surfaces and slow the machine. At the great meeting at Rheims the struggles of competitors to reach the highest altitude—the winner rose but slightly more than 500 feet—proved the difficulty of increasing the steepness of ascent over and above the angle at which the machine must take to maintain a horizontal path.

An efficient machine has a gliding angle of about 1 in 8; that is, when influenced by gravity alone, it will descend one foot for every 8 feet it progresses.

The power needed to propel the machine on a horizontal course is that required to, say, roll a ball of equal weight up a frictionless incline of 1 in 8, and also to overcome frictional air resistance. To maintain stability a speed of from 35 to 40 miles an hour is required.

Let us assume that the machine weighs 500 lbs. with pilot, and that it has to travel at 40 miles per hour to sustain itself. Every second 500 lbs. will be lifted (in *effect*) $\frac{1}{8}$th of 60 feet = $7\frac{1}{2}$ feet. To effect this will require about $7\frac{1}{2}$ horse-power.

Power needed for an Aeroplane.

In order to *rise*, at least one-fifth more power must be added, making 9 horse-power in all. Owing to loss of power in transmission and to screw inefficiency, a further 50 per cent. more power is required, and to overcome air friction and resistance we must allow a further 30 per cent. The engine for a 500 lb. load should therefore develop some 16 horse-power, or about 1 horse-power for every 31 lbs. of weight.

The fact that some flying machines give a much better lift per horse-power is due to a naturally better (more acute) gliding angle, to good design as regards minimizing frictional resistances, to high engine and propeller efficiency, or to a combination of all three. A Wright machine, weighing 950 lbs., is propelled at 40 miles per hour by a 24 horse-power engine, which works out at over 40 lbs. carried per horse-power.

THE MAINTENANCE OF STABILITY.

The flying machine, as at present constituted, is able and liable to topple in any direction. As flight necessitates high speed and considerable elevation above the earth's surface, the maintenance of stability is literally of vital importance. Even under favourable conditions early experimenters found it extremely difficult to counteract the tendency of a glider or power-driven machine to execute unpremeditated dives and somersaults. The history of flight is punctuated by records of more or less disastrous spills resulting directly from the failure of the aviator to keep the machine in such a position that the centre of air-pressure should lie over or coincide with the centre of gravity of the mass in motion.

The problem of balancing an aeroplane is a peculiar one. Hold a sheet of paper horizontally and let it fall. It darts first one way and then another. You can only guess at the direction which it will take finally before alighting. If launched horizontally, it behaves in a most erratic manner. Even a more scientifically designed paper "glider," instead of following a steady downward course, dips up and down, as if influenced by a horizontal rudder. This phenomenon is due to the fact

The Centre of Pressure.

that the pressure on a surface moving obliquely through the air varies in strength at different points on that surface, being greater at the front than at the back edge. The centre of pressure—that is, the point at which the total pressure may be considered to act—is normally situated, in the case of a curved "deck," about one-third of the width of the deck from its front edge; or the pressure may be regarded as affecting the deck on a line drawn transversely through this point.

An increase of speed moves the centre of pressure nearer to the front edge of the oblique surface; a decrease causes it to recede towards the rear edge. A paper glider, as it swoops downwards, is tilted up in front because, though the centre of gravity remains unchanged, the centre of pressure has worked forwards, and the air gets an upward leverage at the front. The tilt gives the glider extra lift, but also slows it; the speed decreases, the centre of pressure recedes, and the original angle of descent is resumed. This cycle of variations may recur many times in the course of a glide.

To keep an aeroplane from pitching longitudinally, provision must be made whereby the centre of pressure may be kept close to the centre of gravity at varying speeds. All biplanes are fitted with an auxiliary movable horizontal surface or surfaces in front of the main decks, and under control of the pilot.

Front Elevators.

Movements of the elevator vary the average angle of incidence of all the sustaining surfaces. Thus, if the aeroplane is gliding downwards, and the pilot wishes to take a horizontal course, he raises the front edge of the elevator. This gives the elevator a greater upward leverage, and increases the angle of incidence of the main decks. To cause a descent, the elevator is tilted downwards, and the general angle of incidence decreased. Gusts of winds coming headways on are counteracted by a proper manipulation of the elevator. It should be understood, however, that the elevator has but little effect in making the machine take a steady upward course. For this an increase in the motive force is required.

(*Photo. Illustrations Bureau.*)

HENRY FARMAN CARRYING A PASSENGER ON HIS BIPLANE.

The Wrights depend entirely on the front elevator for the maintenance of fore and aft stability. They have expressed the opinion that, as the cyclist must learn to balance his cycle, so the aviator must learn to balance his aeroplane. At first the task is not easy, but practice brings a habit of doing the right thing without conscious calculation.

That the lesson can be learnt without great difficulty—at least by persons naturally receptive—has been proved by events. Yet there is much to be said in favour of *automatic* stability systems, which tend to relieve the pilot of the strain entailed by constant watchfulness. In fact, it is hard to conceive what one may style the successful commercial flying machine of the future as a contrivance which will be kept right way up only by virtue of the pilot's unceasing vigilance.

Automatic Stability.

The Voisin, Farman, and some other biplanes carry a horizontal immovable tail in the rear in addition to a front elevator; while monoplanes of all patterns have a horizontal tail as well as a horizontal rudder, which, in the case of these machines, could not well be placed ahead of the main decks, owing to the position of the tractor screw. The tail checks sudden alterations of angle, and generally tends to keep the aeroplane level. A rear horizontal rudder is, however, not so efficient as the front elevator, as it has little effect in checking the speed of the aeroplane when the latter alights. A front elevator is turned up somewhat abruptly just before the machine touches ground, and diminishes the speed while flattening the angle of descent, so that a well-handled aeroplane alights without shock. The action is very similar to that of a bird throwing its head back and opposing its wings almost squarely to the air just as it reaches earth. The monoplane, with its rear elevator, which has little braking effect, is apt to come down heavily and damage the wheeled carriage and the propeller. Thanks, however, to its tail, it has good longitudinal stability if the weight be properly distributed. At one time it was thought that its stability was far inferior to that of the biplane; but M. Blériot, after many experiments, succeeded in overcoming the diving propensities of this type.

Fixed Tails.

Rear Elevators.

Against the tail it may be urged that it decreases speed. The American biplane, the *June Bug*, originally carried a tail. When this was removed the speed was greatly increased. We may observe, too, that the biplanes with double-decked tails are not a speedy class. On the other hand, the monoplane type of tail does not appear to militate against speed.

Though it is as yet early to dogmatize on points relating to aeroplane design, it may be assumed that the tail increases longitudinal stability, but that the front control is extremely valuable. The tailless biplane is more "handy" and easy to manœuvre; the tailed machine more stable, but less easily swung about.

To counteract sideways tilting several systems have been used. The first was to turn the two halves of a deck upwards to form a "dihedral angle" at the middle. This gave stability, but caused a rolling from side to side. The straight-edged deck is somewhat less stable, but is free from rolling. Decks with drooping ends have been used by Mr. Cody, those on his aeroplane having a dip of several inches towards the tips. A partridge when gliding droops its wings, but keeps remarkably steady, so that possibly the third form may prove to be the most suitable. At present the straight deck is in vogue. A very slight dihedral angle is used on the Antoinette monoplanes, as previously by Langley on his model aerodrome, and by Maxim for his big steam-driven machine.

Lateral Stability.

The Voisin biplanes are provided with vertical curtains situated between the main decks and the upper and lower planes of the tail. Monoplanes usually have one or more vertical fins attached to the framework of the rear part of the body. These devices belong to the automatic class, and may be compared to the fins on a torpedo or the deep keel of a sailing ship.

Vertical Curtains.

Though the permanent shape of deck and the employment of curtains and fins may help to prevent tilting, they cannot correct it when it occurs. For this purpose it is necessary to use auxiliary planes attached to the decks or tail, or to alter temporarily the shape of the decks themselves—to "warp" them, as it is now termed. The Wrights warp both main decks by means of a device which will be explained on a later page, bending downwards the end of the deck which is lowest and thereby increasing the lift at that end. To prevent the resulting drag slewing the aeroplane round, the warping mechanism is linked up with the rudder, and moves it simultaneously to the side away from the warped end.

Auxiliary Devices.

The wings of the Blériot monoplane are warped in a somewhat similar manner. The Farman biplane and the Antoinette monoplane have "ailerons," or flaps, attached to the rear edges of the main decks. (See Figs. 4 and 8, pages 23 and 28.) Cody uses a front elevator, the two halves of which can be moved in opposing directions, as well as small balancing planes between the main decks.

On the whole, the problem of maintaining stability has been solved in a considerable degree. This is proved by the fact that the difficulties of balancing a well-designed aeroplane are soon overcome by a clever learner. One of the most remarkable features of the development of aviation has been the sudden rise to fame of aviators after but a few weeks of practice. We must not forget, however, that even the hardiest pilot will not venture forth in rough weather; that the aeroplane is as yet a fair weather machine, which cannot be depended upon to keep steady if struck by a squall, however skilfully handled.

The Wrights, though advocates of the "pilot-balanced" machine, have applied for a patent covering a mechanical device for maintaining automatic stability. In this the human brain is replaced by the pressure of air on a plane as regards longitudinal, and by the movements of a pendulum as regards lateral stability. Compressed air is substituted for muscular action. The plane and pendulum open valves which admit compressed air to an engine operating the elevator and the rudder and warping mechanism. The apparatus has not, so far as is known, been subjected to any actual tests, but it may play a part in the future of aviation.

Mechanical Stability.

The gyroscope has been used successfully on the Whitehead torpedo to maintain direction, and on small vessels to prevent rolling. Also, the Brennan mono-rail railway carriage is balanced entirely by means of a gyroscope. It is thought that the same mechanism might be of use for stabilizing an aeroplane, if arranged so as not to cause too violent strains in the machine. A combination of gyroscope and pendulum has been proposed, whereby the decks or auxiliary planes could be warped or deflected automatically to maintain equilibrium.

The Gyroscope.

Another solution of the problem lies in high speed. The faster a body moves, the less easily is it diverted from its path or turned about on itself. A bicycle driven at twenty miles an hour requires no steering, whereas only an expert could balance the bicycle, without the use of his hands, at walk-

Speed and Stability.

ing pace. Similarly, an aeroplane moving at a hundred miles an hour would be practically unaffected by strong gusts of wind, and not be liable to tilt either longitudinally or transversely. Such a speed would, however, imply the use of small lifting surfaces, which in turn would make landing a difficult matter. Possibly invention may devise some method of altering the area of the decks at will — of reefing them, as it were, during flight, and unreefing when the time comes to alight. It must be confessed that the aeroplane of to-day does not appear to lend itself to any such system as this.

TUNING UP AN ANTOINETTE MONOPLANE PREPARATORY TO A FLIGHT.
(*Photo, Illustrations Bureau.*)

S. F. CODY CROSSING THE BASINGSTOKE CANAL. (*Photo, Topical.*)

He is holding his hands over his head to show the stability of his machine.

THREE VOISIN MACHINE BIPLANES AT THE STARTING-LINE, RHEIMS. (*Photo, Illustrations Bureau.*)

FLYING MACHINES OF TO-DAY.

A REVIEW OF SOME OF THE MOST SUCCESSFUL TYPES, WITH DETAILED DESCRIPTIONS OF THEIR CHIEF FEATURES.

FROM the theory of the flying machine we may now turn to the most prominent examples of its practical application. Inasmuch as at the time of writing the successful heavier-than-air machines are of one or other of two types—the biplanes and monoplanes—we shall not make reference here to the triplanes, multiplanes, helicopters, and flapping machines which are still in the purely experimental stage.

In the present article the term flying machine is synonymous with aeroplane. "Aeroplane" is not a happy term in itself, because planes seldom form part of a flying machine, whereas the curved or cambered deck is always used, at least for the main sustaining surfaces. However, as the word "aeroplane" has established itself, and conveys a distinct impression of a certain type of machine, it must stand.

The dimensions of various machines given in the following paragraphs may be found to differ slightly from the figures given in other publications. This may be explained by the fact that minor alterations are constantly being made by the designers, and that several machines of the same pattern may vary among themselves in detail. It is possible that before these words appear in print some of the aeroplanes described may have undergone considerable modifications, as the result of experience suggesting improvement.

THE WRIGHT MACHINE.

When the history of the development of the heavier-than-air machine comes to be written, the Wright brothers will occupy a position in it analogous to that of George Stephenson in the history of the locomotive. As Stephenson first produced a really practicable locomotive capable of prolonged effort and high speed, so can the Wrights claim to have built the first really practicable flying machine.

Experiments with Gliders.

The story of the Wrights' struggle to master the air has been told sufficiently often to render unnecessary here anything more than a brief *résumé*. The preliminary experiments were begun in 1896, and continued until 1903. During this period were built many

double-decked "gliders," modelled on the lines laid down by Lilienthal and Chanute; the laws of balance were explored; the efficiency of curves with regard to lift and drift examined; and a large number of glides were made, the longest being over 600 feet long, and lasting 26 seconds. The glider used for this particular flight had a supporting area of 312 square feet, a span of 35 feet, and a weight of 117 lbs.

COUNT LAMBERT ON A WRIGHT AEROPLANE. (*Photo, Illustrations Bureau.*)

In 1903 the brothers considered that they had collected sufficient data to justify the application of a petrol motor to a new glider specially built. The engine, built by themselves, had four cylinders of 4-inch bore and stroke, weighed 250 lbs., and developed 12 horse-power at 1,000 revolutions per minute. To support the extra weight, the decks of this machine were given an area about double that of the preceding glider.

The best performance put up during the year was half a mile in just under a minute at a speed of about 30 miles per hour. The lift obtained approximated to ·60 lbs. per horse-power developed by the engine.

An Engine fitted.

The next year the Wrights shifted the scene of operations from the neighbourhood of Chesapeake Bay—where the prevailing winds had been particularly favourable for gliding experiments—to their home at Dayton, in Ohio, and proceeded to build a second machine. With this—driven by a 17 horse-power engine—they made many flights, the record for the year being rather more than 3 miles in 5 minutes 17 seconds, at a speed of 34 miles

per hour. They also had the satisfaction of completing an aerial circuit for the first time.

Encouraged by their success, the Wrights built, in 1905, the now famous "White Flier"—the "Rocket" of aviation. This machine had a deck area of 625 square feet, and mounted a 24 horse-power 250-lb. gasolene engine, which drove two large wooden propellers, 6 feet in diameter, in opposite directions, by means of chain gearing. The weight of the machine "mounted"—that is, with pilot "up"—totalled 925 lbs.

The First Great Human Flights.

During the months of September and October the "White Flier" made some remarkable journeys, all the more remarkable from the fact that three years elapsed before they were beaten by those of any other machine. The following is the record :—

Date.	Distance.	Time.
September 26, 1905	11⅛ miles	18 min. 9 sec.
,, 29, 1905	12 ,,	19 ,, 55 ,,
October 3, 1905	15¼ ,,	25 ,, 5 ,,
,, 4, 1905	21 ,,	33 ,, 17 ,,
,, 5, 1905	24½ ,,	38 ,, 3 ,,

Owing to the privacy with which the flights were conducted and to the silence of the local press, the performances were generally discredited in France, where Captain Ferber, Gabriel Voisin, and M. Ernest Archdeacon had for some years been following up the gliding experiments of Lilienthal and Octave Chanute. Sufficient independent testimony was forthcoming, however, to establish as a matter beyond doubt that the Wright aeroplane had flown with a passenger for a considerable distance, had executed flights in any direction desired, and had come safely to ground at high and low speeds ; that, in short, there was no reason to disbelieve the statements recorded by the Wrights.

During 1906 public curiosity compelled the brothers to content themselves with improving the smaller details of a machine which they considered to have a commercial value. In 1907 they made several flights, and opened negotiations with several Governments for the sale of their invention, and in the following year brought their Flier to France.

Record-breaking in France.

After some preliminary tuning-up flights, Wilbur Wright stayed in the air for 19 minutes 48⅗ seconds on September 5, 1908. On the 21st, he broke all his own records handsomely with a flight lasting 1 hour 31 minutes 25⅘ seconds, and caused a tremendous increase of popular interest in aviation. Two months later he travelled 62 miles in 1 hour 54 minutes 53⅖ seconds ; and on the last day of the year won the Michelin Trophy with a flight which lasted 2 hours 20 minutes 23⅕ seconds, and covered a distance of 77½ miles. (This was the officially measured distance. The actual distance travelled was considerably greater.)

These really astonishing feats, which remained unbeaten for seven months,* resulted in orders for Wright aeroplanes being placed by several Governments and many private individuals, and at the present moment more machines of this type exist than of any other. A description of its main features will therefore be of interest.

The Machine.

The decks are about 40 feet long and 6½ feet deep from front to rear, giving a total bearing surface of about 530 square feet (in some of the most recent machines the surface has been reduced considerably). The framework of each deck consists of two parallel main cross members—one running along the front edge, the other about 4 feet 3 inches in the rear—and connected at the ends. These support arched ribs, 15 inches apart, slightly curved, and composed of upper and lower slats separated by blocks and approaching nearer to one another towards the back edge. They pass

* On August 7, 1909, M. Sommer flew for 2 hours 27 minutes 15 seconds on a Farman biplane, to be in turn beaten by Henry Farman (on a Farman biplane) on August 27, with a flight lasting 3 hours 4 minutes 56⅗ seconds (180 kilometres = 112 miles).

round the after cross member. Above and beneath the ribs is fastened rubbered cloth, to form a double-surfaced deck.

The two decks are held apart by a number of wooden uprights attached to the cross members of the decks. The three rear supports at each end are merely hooked on, so as to allow of a small amount of movement. The whole structure of the body is suitably stayed with diagonal wires to form a truss.

About 8½ feet to the rear of the main decks are two vertical rudders for lateral steering, 2 feet wide and nearly 6 feet high. Cross-spars link them together.

Steering and Balancing Planes.

For vertical steering and balancing, a couple of horizontal planes are mounted 10 feet or so in front of the main decks, similarly interconnected and pivoted on vertical extensions of the long skates on which the machine rests. Between the planes are two semicircular fixed planes to assist in the maintenance of stability. A lever, held in the pilot's left hand, controls the elevation rudders.

The most interesting feature of the Wright machines is the device for warping the wings, either independently of or in conjunction with movements of the steering rudders. The accompanying diagram (Fig. 1) will assist to explain its action. A lever (R) on the pilot's right hand is connected by a bar (A) to the rudder gearing, and pivoted at the bottom as regards forwards and backwards motion on the end of a rod (B), which can be revolved sideways in sockets. At the rear

How the Decks are warped.

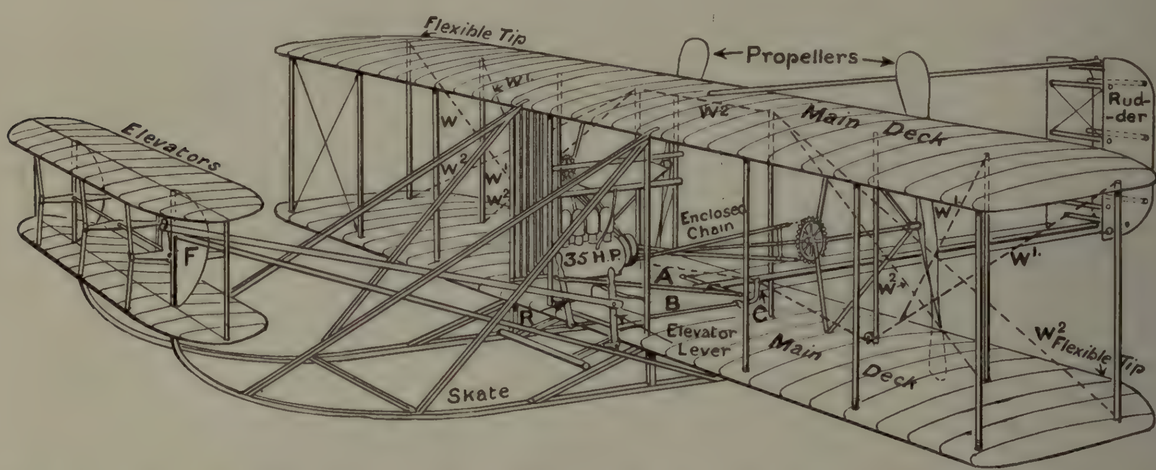


Fig. 1.—DIAGRAM SHOWING THE VARIOUS PARTS OF THE WRIGHT AEROPLANE, AND THE METHOD OF WARPING THE DECKS.

end of this rod is a short vertical arm (C) from the top of which wires (W^1W^1) run right and left several feet along the upper side of the bottom planes, and then pass upwards through pulleys to the tops of the rear wooden uprights at the ends of the decks. Sideway movements of the lever R flex downwards one or other end of both decks. A secondary series of wires (W^2W^2) connecting the bottoms of the end uprights *viâ* the under side of the top decks cause a reverse flexure at the other end of the decks. Thus, if the lever be put over to the left, the right tips are drawn down and the left tips bent up. By this simple system, which is largely responsible for the "handiness" of the Wright machines, the pilot is enabled to make the decks assist the rudder, or the rudder assist the decks, for preserving balance and for rounding curves. The reader will have no difficulty in under-

standing that the downward flexing of one end of a deck will make that end rise and lose speed, and that the flattening of the other end will diminish "lift" and increase speed. While counteracting a tilt the drag put on one side slews the machine on its vertical axis, and this has to be counteracted by a simultaneous moving of the steering rudders in the proper direction. Again, the rounding of a curve with the assistance of the rudder alone would produce an extra lift at the outside end, where the speed is greatest; and here the ability to flex the inside end downwards comes in useful. Primarily, the flexure is for the purpose of stability; incidentally, it assists steering.

A WRIGHT AEROPLANE ON THE STARTING-RAIL.

In the rear is the tower with weight discs raised. To the right of the machine is the carriage on which it is moved to the starting-rail after a descent.

(Photo, Topical.)

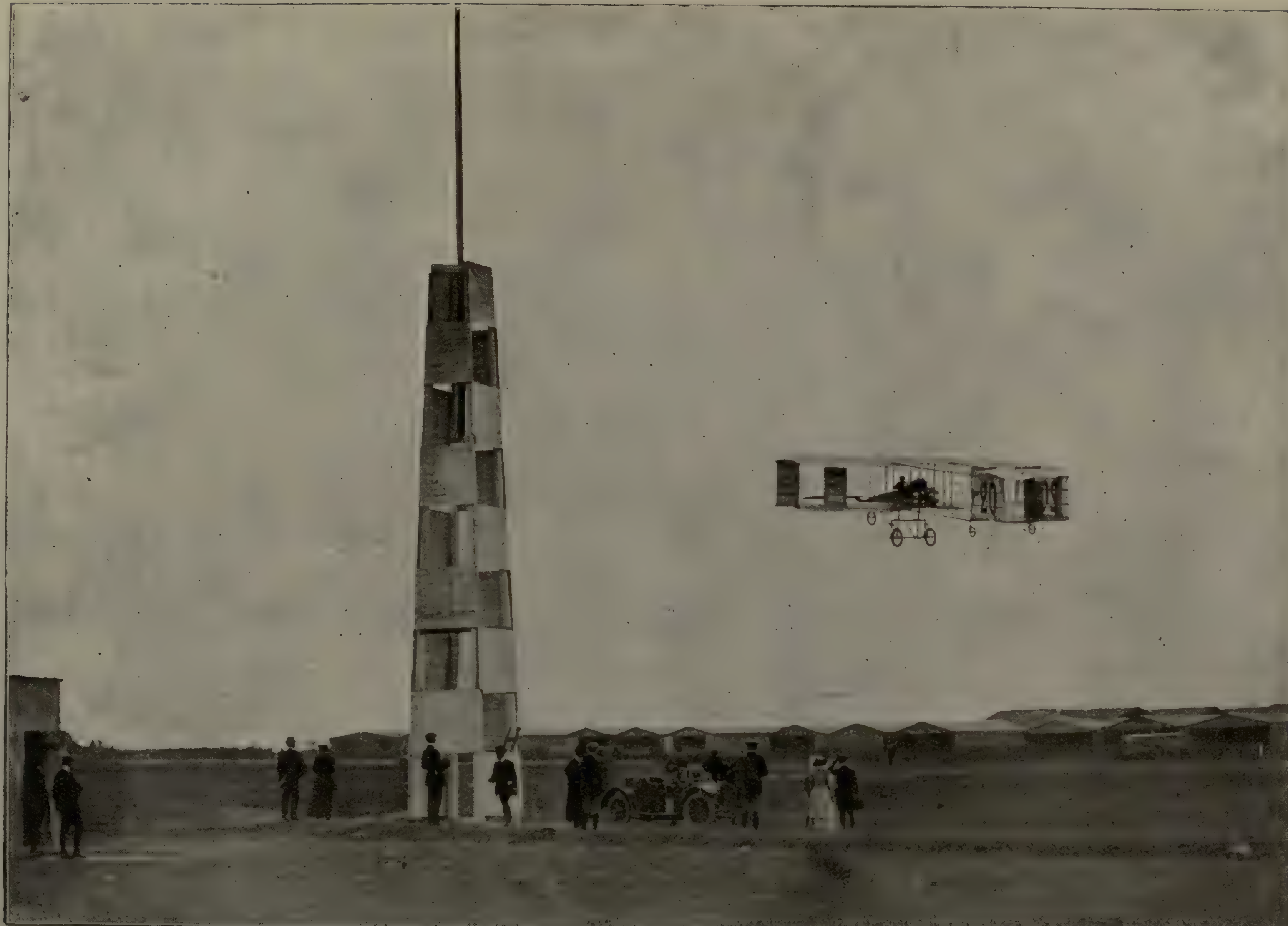
Engine and Propellers.

The four-cylinder engine, which is described in another place, transmits its power to twin-screw propellers behind the decks through chains, one crossed so that the propellers shall revolve in opposite directions. The indirect drive is taken advantage of to use large propellers turning at little more than a quarter of the speed of the engine. Two screws, working in opposite directions, assist stability by eliminating all gyroscopic action.

The Wrights still adhere to their original system of starting their machine by means of external help. In place of the usual wheeled carriage attached to the under-side of the body are found a couple of long wooden runners or skates, which prove extremely efficient for absorbing the shocks of landing.

How the Machine is started.

Preparatory to a flight the machine is placed on a wooden trolley having two small wheels tandem, running on a rail about 23 yards long. Behind the machine, and in line with the rail, is a wooden tower, inside which are a number of iron discs weighing about 1,500 lbs. From the discs a rope passes over a pulley in the tower top, down the tower, under a pulley at the base, along the ground to a pulley at the far end of the rail, and back towards the carriage, to which it can be attached when the discs have been hoisted to the summit of the tower. To make a start, the pilot sets the engine going at full speed, and releases a catch which had previously prevented the carriage from moving. The machine darts forward, and in a few yards has attained sufficient speed to lift it from the rail, against which, however, it is kept by depressing the elevators. On reaching the end of the rail it is shot from the carriage, and, the elevators being now quickly raised, rises into the air. Against the wind the machine can be started along the rail by the propellers without the aid of the weights.



PAULHAN DOING RECORD FLIGHT ON VOISIN BIPLANE AT RHEIMS. *(Photo, Illustrations Bureau.)*

THE VOISIN BIPLANE.

This machine, which came into prominence at the beginning of 1908 as the first successful rival to the Wrights' Flier, is based, as regards its general lines, on the cellular glider devised in 1898 by Mr. Octave Chanute. It consists of two superposed main decks, 33 feet by 6 feet 5 inches (total area about 450 square

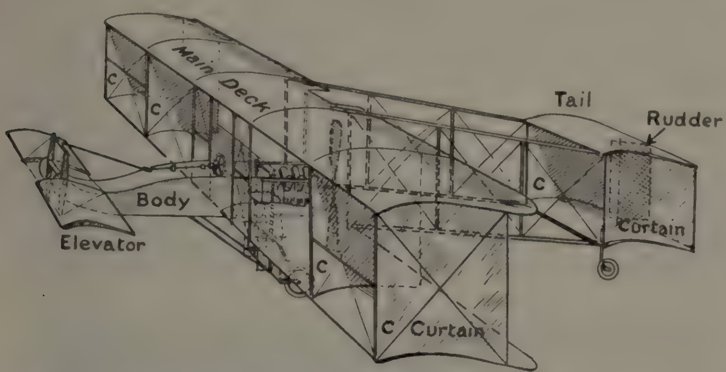


Fig. 2.—DIAGRAM OF VOISIN BIPLANE.

feet), set 5 feet apart; two smaller superposed decks, 8 feet by 6½ feet (total area about 110 square feet), connected to the main decks by a rigid framework, and situated about 13 feet to the rear to form a tail; an elevator (total area about 50 square feet) mounted 4½ feet in front of and on a level with the lower main deck on the end of a projecting girder, in which are situated the pilot's seat and the control gear. The "tail" is closed at each side by two vertical curtains, and the main decks are united by four vertical curtains, extending about three-quarters of the distance from the front of the trailing edge. The purpose of these curtains is to give vertical stability and obviate the need for warping of the decks or the use of balancing planes. A single vertical rudder inside the tail serves for horizontal steering (Fig. 2).

Power is supplied by a 50 horse-power engine geared direct to a single high-speed propeller astern of the main decks. The decks are all curved—the curve depth being one-fifteenth of the fore and aft width of the deck—and covered on the lower side only of the ribs, which are attached to two main cross-spars. The elevator is double surfaced, its horizontal pivot passing between the two surfaces.

The machine runs on four wheels, two under the main decks and two under the tail. When at rest, the decks make an angle of 8° with the horizontal, and lift at a speed of about 30 miles per hour. When the machine has risen into the air and the speed is increased, this angle diminishes to about 2°.

Voisin Steering Control.

A very interesting feature of the Voisin aeroplane is the steering control, of which a diagrammatic sketch (Fig. 3) is given. A steering wheel of motor-car type operates a horizontal rod, which can be moved backwards and forwards, and also revolved, in sockets on the body. The rod is connected

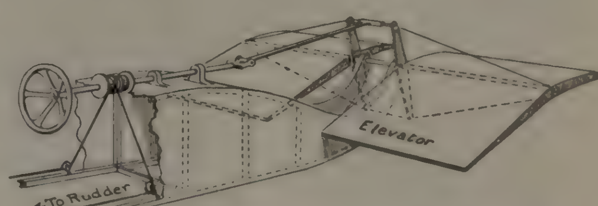
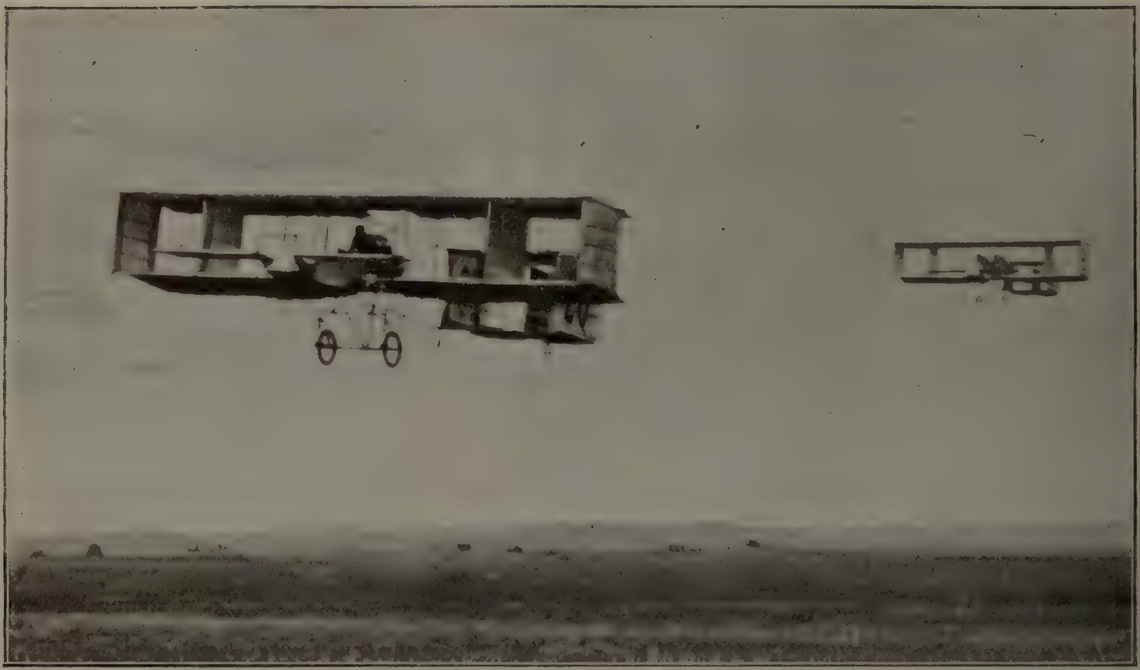
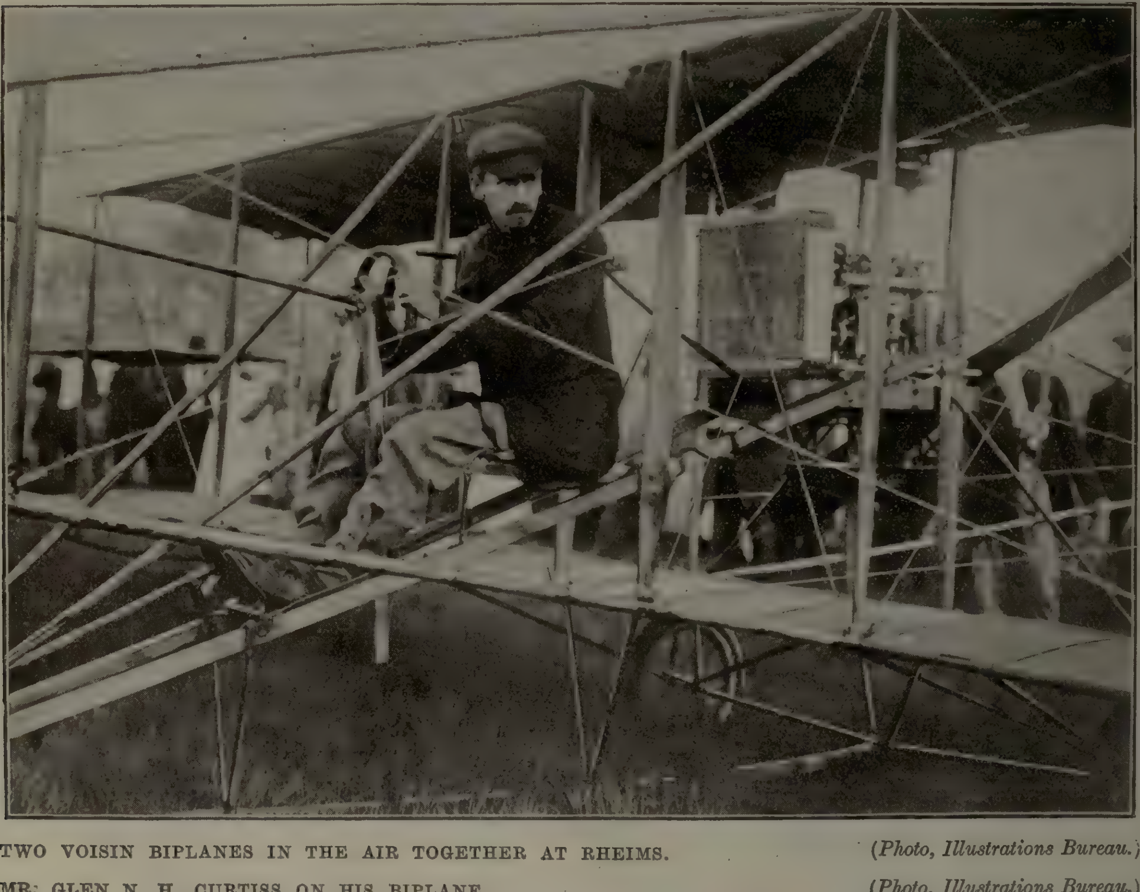


Fig. 3.—DIAGRAM SHOWING STEERING CONTROL OF VOISIN BIPLANE.

through a universal joint and a second rod to the elevator. On a drum mounted on the steering pillar are wound the wires controlling the vertical rudder in the tail. The driver therefore controls both vertical and horizontal movements of the aeroplane by the same steering wheel. The Voisins claim that the cellular principle is inherently stable, and that it makes for ease of control and safety in descent. The utility of vertical curtains has been questioned. It is maintained in some quarters that they decrease





TWO VOISIN BIPLANES IN THE AIR TOGETHER AT RHEIMS. *(Photo, Illustrations Bureau.)*

MR. GLEN N. H. CURTISS ON HIS BIPLANE. *(Photo, Illustrations Bureau.)*

This machine is the lightest and swiftest of the biplanes that competed at Rheims.

speed and make the machine "unhandy" in rounding corners. The popularity of the type, the quickness with which the novice learns how to handle it, and its undoubted longitudinal stability, are decided points in its favour. Nine Voisin machines, having 540 square feet of supporting surface, and weighing, in flying order, 1,250 lbs., were entered for the Rheims meeting.

A FARMAN BIPLANE. (*Photo, Topical.*)

Observe the flaps at rear of the decks, used for maintaining lateral balance.

THE FARMAN BIPLANE.

This type of machine (Fig. 4), which, driven by its inventor, carried off the Grand Prix for distance at Rheims with a flight of 180 kilometres (112 miles), won the prize given for carrying the greatest number of passengers (two), and took second place in the altitude contest, is designed on Voisin lines, but dispenses with vertical curtains. The front elevator is placed somewhat high. To assist steering and lateral stability, the rear ends of the main decks are provided with hinged flaps, which hang down when the aeroplane is at rest, but rise during flight into a horizontal position. Flexing them up or down enables the pilot to steer the machine and keep it on an even keel. As our photographs show, the carriage under the main decks has four wheels and two long skates. The latter serve to take the main shock of alighting when the impact is sufficiently great to press the wheels a certain distance upwards on their flexible joints.

The weight of a Farman aeroplane is about 1,250 lbs., the area of supporting surface about 475 square feet.

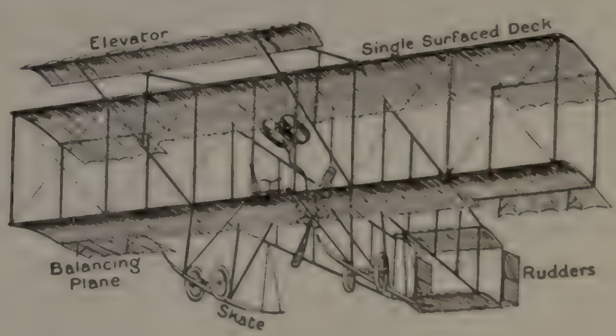


Fig. 4.—DIAGRAM OF FARMAN BIPLANE.

THE CURTISS BIPLANE.

This is the smallest of double-decked machines, having but 280 square feet of supporting surface, and weighing only 550 lbs. Yet it won the Gordon Bennett race at Rheims for the fastest flight of 20 kilometres (in 15 minutes 50⅗ seconds), and took the first prize for the fastest 30 kilometres, and the second for the fastest 10 kilometres. The chief features of this aeroplane—which is of American origin—are two superposed single-surfaced main decks, 28¾ feet long and 4 feet 6 inches wide, 5 feet apart; a double-decked front elevator (24 square feet); a horizontal tail (12 square feet); a vertical rear rudder; a single propeller, 6 feet in diameter; and two balancing planes situated between, and partly projecting beyond, the tips of the main decks. The planes are flexed by levers operated by movements of the pilot's body. The elevator and rudder control is practically the same as that used on the Voisin aeroplanes. The decks are covered on the lower surface with rubberized silk, pockets of which enclose the ribs above. An engine of 30 horse-power, weighing, with radiator, about 200 lbs., is used.

The Curtiss is essentially a one-man machine, built for speed rather than for lifting capacity.

THE CODY BIPLANE.

At the opposite end of the scale from the Curtiss is the Cody machine, the heaviest and largest aeroplane yet built, and also distinguished as being the first successful flier of British construction. The main decks, double surfaced, 52 feet long by 7 feet 6 inches wide, have an area of 775 square feet; and the front elevators, which also take part of the load, an area of 150 feet. The two vertical rudders are disposed at equal distances fore and aft of the main decks (Fig. 5).

The elevator is in two parts, each of which can be moved independently of the other to serve the purpose of balancing planes. Steering is assisted by warping the decks. Both vertical and horizontal rudders are operated by a single steering wheel immediately in front of the pilot.

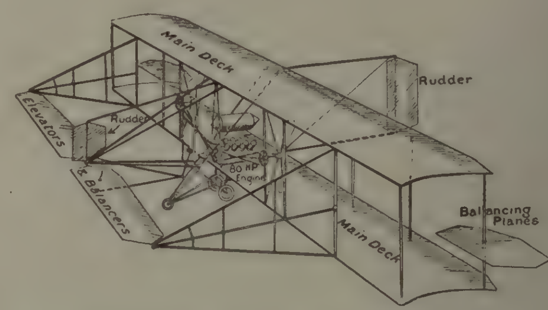


Fig. 5.—DIAGRAM OF THE CODY BIPLANE.

An 80 horse-power "E.N.V." engine drives two propellers mounted between, and near the forward edges of, the main decks. The propellers are peculiar in being wider at the base than at the tips.

So large and heavy is the Cody aeroplane—with pilot it weighs about a ton, or half as much again as the Voisin machine—that the decks have been so designed that two end sections, 16 feet long each, can be removed. The girder supporting the elevator also is detachable, and the rear rudder frame folds back against the body.

After many unsuccessful attempts Mr. Cody has at last evolved an efficient machine, capable of great speed. It has flown at nearly 50 miles an hour. On September 8 it put up a record for a cross-country flight by covering over 40 miles in the neighbourhood of Aldershot, not coming to ground until the petrol supply was quite exhausted. At one point an altitude of 600 feet was attained.

Monoplanes.

Coming now to the other main class of flying machines, the *Monoplanes*, we may pay attention to three types—those known as the Blériot, Antoinette, and the Esnault-Pelterie. In general appearance they have, when viewed from a distance, a decided resemblance to a bird.

Indeed, as shown in some photographs published, the two-winged monoplane, with its long trailing tail, might well be mistaken for a gigantic hawk hovering afar off in mid-air.

M. BLÉRIOT CROSSING THE BORDEAUX EXPRESS DURING HIS CROSS-COUNTRY FLIGHT FROM ÉTAMPES TO ORLEANS.
(Photo, Topical.)

THE BLÉRIOT MONOPLANE.

The Channel flight has brought into prominence the successful Blériot short-span machine (No. XI.), and its less fortunate but considerably larger rival, the Antoinette. The aeroplane on which M. Blériot crossed the "silver streak" is the smallest but one of all flying machines as regards sustaining surface, for the two wings have a total area of but 150 square feet. Since the weight of machine and pilot is over 700 lbs., every square foot of deck has to support nearly 5 lbs. To obtain the necessary lift a considerable angle of inclination of the decks and high speed are needed. The last factor is attained more easily on a monoplane by virtue of the absence of the uprights, cross-bracing, etc., which form necessary parts of a biplane, and offer considerable head re-

A BLÉRIOT MONOPLANE IN FULL FLIGHT. *(Photo, Illustrations Bureau.)*

AN ANTOINETTE MONOPLANE IN FLIGHT. (Photo, "The Sphere.")

Observe the end shape of the decks.

sistance. We may add that the builders of monoplanes seem to have devoted special attention to the shaping and finish of the decks, which in all cases are covered on both surfaces, and brought to a sharp edge in front.

M. Blériot's small monoplane (Fig. 6) has a span of 28 feet and a length over all of 25 feet. The decks, which have the rather low aspect ratio of 4¾ to 1, are rounded at the ends, and

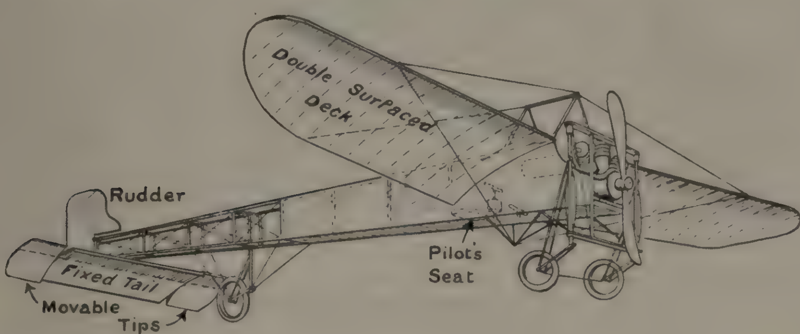


Fig. 6.—DIAGRAM OF BLÉRIOT MONOPLANE.

are detachable from the body for convenience of transport. The body is a trussed frame about 20 feet long, tapering to the rear. At the front end is placed the three-cylinder Anzani engine, geared direct to a 6-foot 6-inch wooden propeller. Immediately behind the engine is the petrol tank, and behind that again the pilot's seat, which is in line with the rear edge of the decks. Near the after end of the body truss, and underneath it, is the fixed tail, with two movable elevating tips. At the extreme end is a vertical rudder. Balancing is effected by warping the main decks. The wheeled carriage, of which a sketch is appended, has some points of interest (Fig. 7).

The No. XII. monoplane is a somewhat larger machine, having a deck area of 230 square feet. In point of weight it exceeds all other flying machines—except Cody's—with its 1,300 lbs. Nevertheless it has carried two passengers besides the pilot.

In the latest model the petrol tanks and lubricating oil reservoirs are housed between the two surfaces of the wings, and so are completely out of sight; and a 50 horse-power engine is used.

As a class the Blériot monoplanes are very speedy. The Channel was crossed at an average velocity of 45 miles per hour. At Rheims, M. Blériot made the fastest time for a single lap of the 10 kilometre circuit.

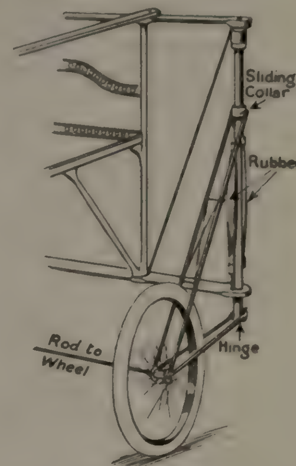


Fig. 7.—WHEELED CARRIAGE OF BLÉRIOT MACHINE.

THE ANTOINETTE MONOPLANE.

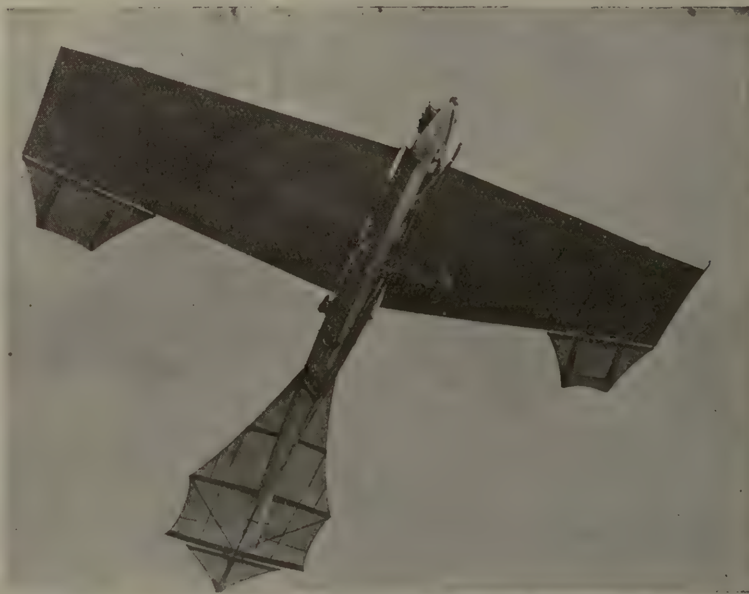
The Antoinette monoplane (Fig. 8) has distinguished itself for its speed and wonderful capacity for attaining great altitudes. During his second attempt to cross the Channel, M. Latham was credited with a velocity of nearly 55 miles per hour. In deck surface and weight the Antoinette, with its 575 square feet and 1,250 lbs., equals the larger biplanes.

The wings, which have a spread of about 40 feet, project from a boat-shaped body, along the sides of which run the tubes of the engine radiator. The body tapers away to the rear, on which are set two vertical and one horizontal rudder, besides two fixed vertical stability planes. The decks are inclined at a slight upward angle to each other, and are covered with rubbered silk on both surfaces. To maintain stability, two small wings, or ailerons, are attached to the back of the decks, near their ends.

The vertical steering is effected by a wheel at the pilot's right hand, balancing by a wheel at his left, and horizontal steering by a lever operated by the foot.

The engine is a 50 horse-power Antoinette, driving a single screw 7 feet 2 inches in diameter at 1,100 revolutions per minute. A large skate, projecting in front of the wheeled carriage, helps to absorb the shocks of descent.

At the Rheims meeting the Antoinette monoplane showed to advantage, by winning the Prix d'Altitude, the second and fifth prizes in the Grand Prix distance contest, and the second prize for speed.



LATHAM'S ANTOINETTE AS IT APPEARED FROM BELOW.

(*Photo, Illustrations Bureau.*)

THE "R.E.P." MONOPLANE.

This monoplane, built by M. Robert Esnault-Pelterie, has decks of 215 square feet area, and weighs about 950 lbs. Its spread is 30 feet and its length 25 feet. Both decks can be warped to maintain balance. A horizontal movable tail and vertical rudder are placed at the rear end of the body. At the forward end is a 50 horse-power "R.E.P." seven-cylinder air-cooled engine, driving a large four-bladed tractor screw. (This interesting engine is described in the next article.) The body is covered in with fabric to decrease the air resistance.

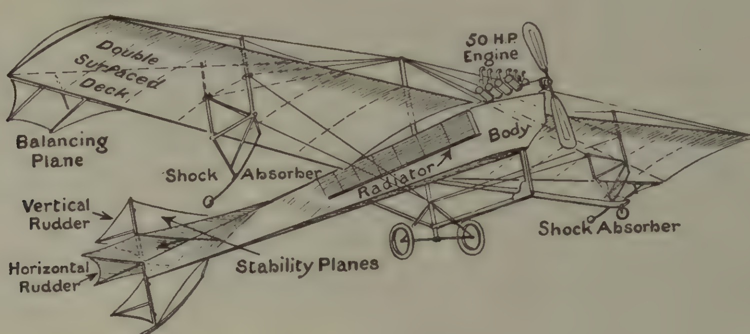


Fig. 8.—DIAGRAM OF ANTOINETTE MONOPLANE.

AERONAUTICAL ENGINES.

A review of some of the most interesting of the internal combustion engines that have been designed specially for use on flying machines.

THE provision of sufficient motive power and the reduction of weight to a minimum are two problems which have exercised the constructors of flying machines no less than that of designing efficient supporting surfaces. The Wrights, when they first decided to apply power to their gliders, were confronted by the fact that there was not on the market an engine light enough for their particular purpose. Sir Hiram Maxim had, it is true, lifted his great experimental machine from the ground with the aid of a steam engine which developed a horse-power for every 6 lbs. of avoirdupois, boilers and all fittings included. Professor Langley subsequently propelled a model aerodrome with a steamer that gave an output of 1½ horse-power for its 7 lbs. But the difficulty of keeping these engines supplied with water and fuel, and certain other considerations, had made it evident that another form of prime mover was needed for aerial flight. The development of the internal explosion engine on the motor car prepared the way for the flying machine. Most of the aeronautical engines of to-day are, in their general principles, four-cycle motor-car engines greatly improved in the matter of weight, and modified in detail wherever modification makes for lightness. The designer has had it in his favour that aerial engines are not called upon to withstand the vibrations set up by wheels passing over rough roads, or the strains caused by clutches, gears, etc. On the other hand, he has had to be very careful not to cut weight down to danger point, as a failure of any part of the engine may have disastrous consequences. A very large proportion of aviators' involuntary descents to earth has been due to engine failures; and the same cause was responsible for both of M. Latham's swoops into the Channel. If anything goes wrong with a car engine—which is a rare occurrence nowadays—the driver can stop without risk to investigate. But the aerial motor must be even more *reliable* than the car engine. In addition, it must be extremely *efficient*, for if its power falls below a certain minimum the machine must come down too; and it must be *automatic*, supplying itself regularly, and inde-

pendently of human agency, with fuel, lubricating oil, and electric current.

The parts of an aeronautical engine are necessarily cut as fine as possible in regard to mass. The cylinder walls are reduced to the minimum thickness. Valves, pistons, piston-rods, cranks, and gearing are made light. To avoid carrying the pound or so of water per horse-power for cooling the engine, air cooling is resorted to widely. Where water is employed, the jackets and radiators are of very thin metal. (At present it seems to be a moot point whether the weight saved by air-cooling is not more than offset by a loss in power.) To increase efficiency the cylinders are often provided with auxiliary exhaust ports, and silencers are omitted.

How Weight is saved.

The need for a fly-wheel of considerable mass on a four-cylinder engine has brought the five, six, seven, eight or more cylinder engine, giving a more or less constant turning effect and perfect balance into favour, as enabling fly-wheels to be dispensed with.

Automatic lubrication, by means of a force pump, is a *sine quâ non*. The aviator's attention and hands are too fully occupied in the maintenance of direction and balance to be available for watching and regulating sight feeds, hand pumps, and gauges. The light mechanical oil pumps now used have been developed to a high pitch of perfection and reliability.

Lubrication.

Under the head of carburation some reduction of weight has been effected by replacing the carburettor and large induction pipes by a pump delivering unatomized petrol through very small pipes direct to the cylinder. This method is, however, considered to be somewhat wasteful of fuel, and to produce overheating, so that its use is decreasing in favour of the spray carburettor. Magneto and accumulator *ignition* are used, either separately or in combination.

Carburation.

The aerial motor will doubtless be much improved in the future. Sir Hiram Maxim expects that its weight will be reduced, at no distant date, to $1\frac{1}{2}$ lbs. to the horse-power. Even as at present developed it has shown itself capable of excellent work, despite the fact that, as compared with the car motor, it gives from twice to three times the amount of power per pound weight. It can hardly be doubted that the inventiveness resulting from the necessity for lightness of construction will in due course react upon the motor-car engine, and cause a great reduction in the avoirdupois housed under the "bonnet." One must, nevertheless, not lose sight of the fact that a very light engine of high quality must be an expensive engine, as it requires the best of materials and the most careful manufacture, which last entails highly-skilled labour.

We may now review briefly some of the many types of engines which merit notice, paying special attention to distinctive features. In most cases the weight of the engine is given. The figures are, however, hardly a fair criterion for comparison, as some makers include in their totals items which are excluded by others.

FOUR-CYLINDER ENGINES.

In this class the place of honour will be given to the Wright (Fig. 1) type of engine, which, however, has no very striking features. The four cylinders, arranged tandem in the usual motor-car fashion, have a bore of 110 mm.* and a stroke of 92 mm. The valves are situated on the top of the head; the inlets are automatic, the exhausts operated by overhead rocking levers. Water cooling is used, water being forced through the four separate water jackets by a pump mounted on the forward end of the crank shaft. Our illustration shows the position of the high tension

The Wright Engine.

* For the edification of the reader who is unacquainted with the metric system of measurement, it should be stated that 25 millimetres (mm.) equal one inch.

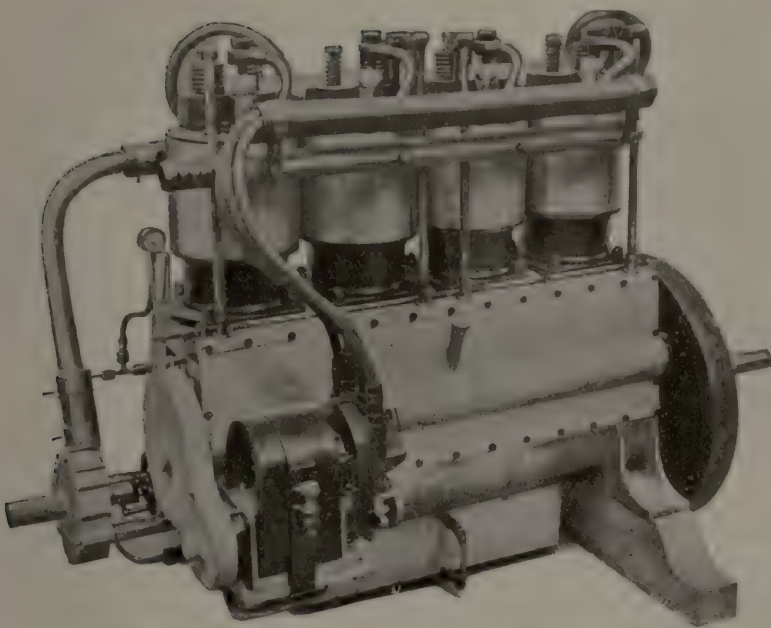


Fig. 1.—THE WRIGHT FOUR-CYLINDER 35 HORSE-POWER ENGINE.
(*Photo, Topical.*)

magneto driven off the cam shaft. On the farther side of the crank-case is a small worm-gear driven pump, which delivers petrol direct into the cylinders, and a pump for forcing lubricating oil from a reservoir in the bottom of the crank-case through the main bearings. A very simple radiator, of flat copper tubes, is mounted vertically on one of the stanchions separating the decks. It is to the credit of the Wrights that they designed and built the first petrol engine ever used for mechanical flight. So far, they have not, apparently, seen any good reason for abandoning the simple type with which they won their first successes.

The Green Engine.

The Green engine, built for the Green Motor Patents Syndicate by the Aster Engineering Company, has, in addition to the fact that it is one of the at present very few British-made aeronautical engines, several interesting points. It is extremely light in proportion to its power. The nominal 35 horse-power type (Fig. 2) scales but 148 lbs., so averaging about 4 lbs. to the horse-power, fly-wheel included; the 60 horse-power model weighs 236 lbs. Lightness has been obtained without sacrificing strength by very careful design. The cylinders and valve ports are cast in high-grade steel, and machined inside and out to the maximum thinness advisable. The water jacket, pressed out of thin copper sheet, encloses completely the upper part of the cylinder and valves. A grooved flange projects from the cylinder to accommodate a rubber ring, against which the slightly bell-mouthed open end of the jacket presses, and so a water-tight joint is obtained. The heat of the engine has no effect on the

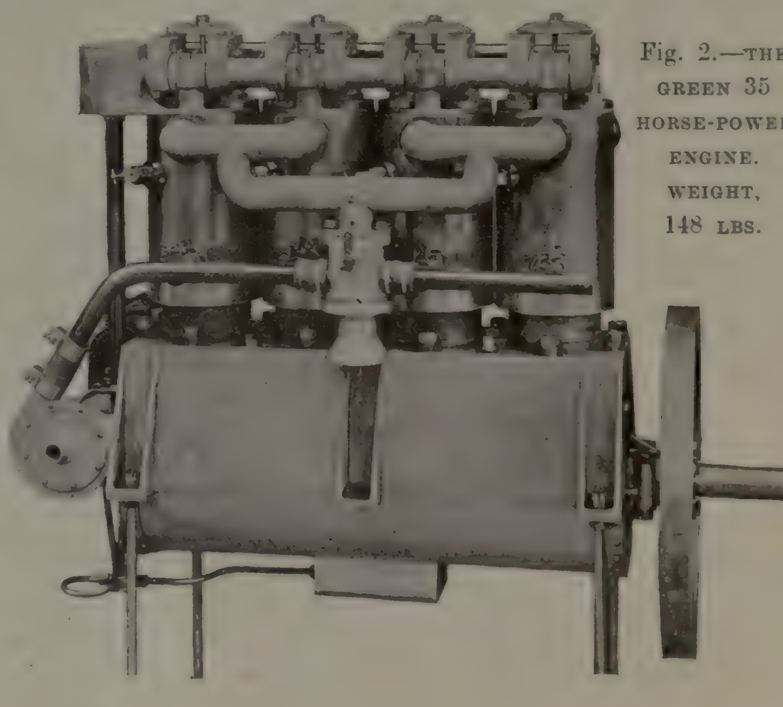


Fig. 2.—THE GREEN 35 HORSE-POWER ENGINE. WEIGHT, 148 LBS.

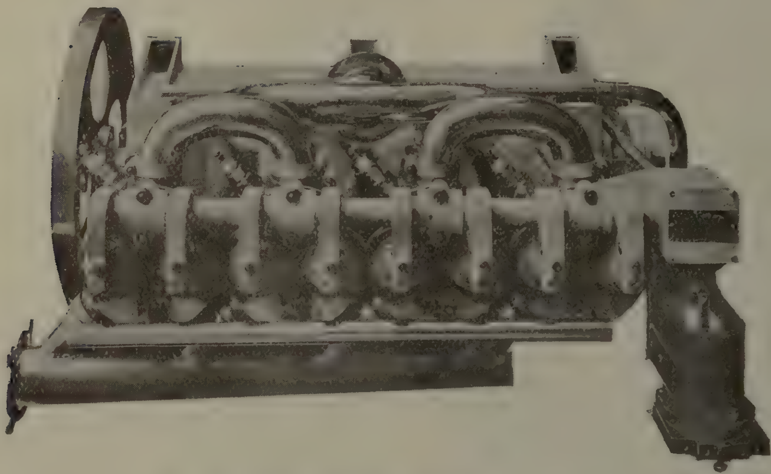


Fig. 3.—THE GREEN ENGINE, TOP VIEW.
The cam shaft and rocking levers for operating the valves are enclosed in an oil-tight casing.

crank-case itself—a very desirable feature. Space is left between the bolts and the columns through which they pass for conducting lubricating oil from a force pump to the bearings. When the engine is running the only visible point in motion is the fly-wheel.

An 80 horse-power eight-cylinder V type engine comprising the same features was supplied to the War Office for a dirigible balloon.

Our list must include the Anzani three-cylinder engine, as it was one of these that brought M. Blériot safely across the Channel in his memorable flight of July 25, 1909. The cylinders, of 100 mm. bore and 150 mm. stroke, radiate at angles of 60° from the upper half of the crank-case. The draught from the propeller serves to carry off excess heat, so water-cooling is here dispensed with. The exhaust valves are assisted in scavenging by

The Anzani Engine.

outer surface of the rubber. Interchangeable valves, in detachable cages, fastened down on the valve ports by internal screwed locking rings, are used. All joints round pipes and ports are made water-tight by pressing the copper jacket against the metal of the cylinder by suitably shaped screwed nipples and washers.

The valve-operating cam shaft runs along the top of the cylinders, and is driven through a vertical spindle (seen on the left) and bevel gear. An oil-retaining casing, which encloses the crank shaft, affords bearings for the eight rocking levers for operating the valves. The casing is divided into two halves vertically, and can be rotated on the shaft when holding-down clamps have been undone, so giving easy access to the valves. (Fig. 3.)

The main bearings are connected directly to the cylinders by vertical bolts passing through columns in the cross divisions of the upper half of the aluminium crank-case. The driving stress is thus taken off the

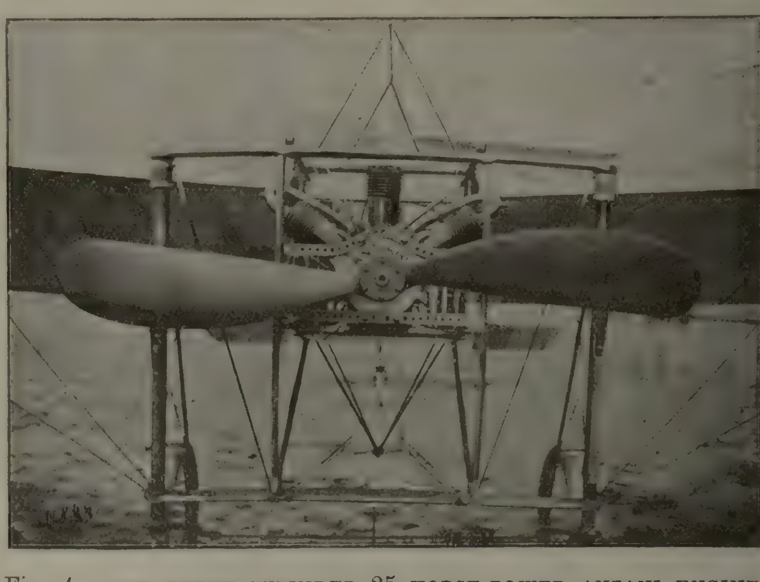


Fig. 4.—THE THREE-CYLINDER 25 HORSE-POWER ANZANI ENGINE, WHICH TOOK M. BLÉRIOT ACROSS THE CHANNEL.
(*Photo, Topical.*)

auxiliary ports in the cylinder walls, uncovered by the piston at the end of the stroke. The engine develops 25 horse-power, and has

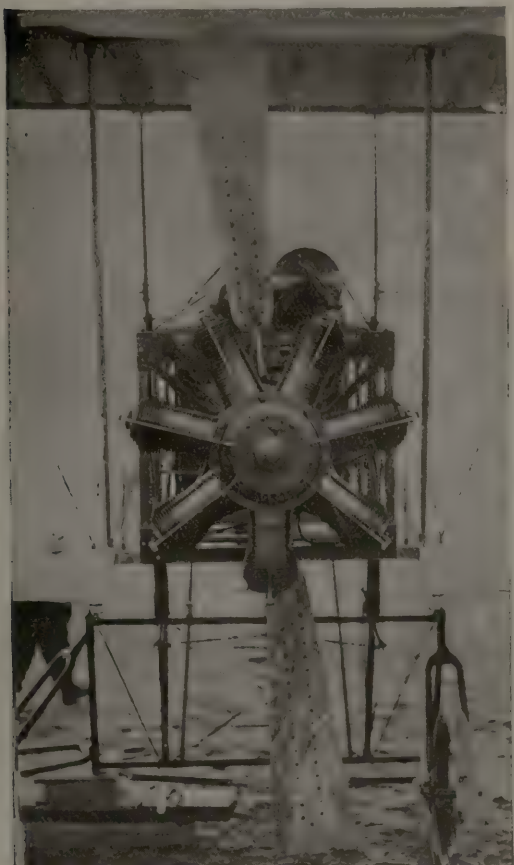


Fig. 5.—"GNOME" REVOLVING SEVEN-CYLINDER ENGINE ATTACHED TO PROPELLER, WHICH IT CARRIES ROUND WITH IT.

This engine develops 50 h.p., and weighs only 160 lbs. Mr. Henry Farman used a "Gnome" for his record flight of 112 miles at Rheims.

(*Photo, Topical.*)

the merit of being extremely compact. Motors of this type are fitted to several Blériot machines. (Fig. 4.)

We now come to a very interesting class, the five and seven cylinder star-shaped engines, with cylinders radiating at equal distances from the circumference of a central crank-case. The advantage of an odd number of cylinders thus arranged is that it gives explosions at equal distances in continuous sequence. Thus, the firing order of the cylinders of a seven-cylinder engine is 1, 3, 5, 7, 2, 4, 6, 1, 3, 5, etc. In the case of six cylinders, arranged in star fashion, there must either be a 1, 2, 3, 4, 5, 6 sequence of explosions during one revolution, and no explosions during the next, or the explosions must occur at irregular intervals: 1, 3, 5, 2, 4, 6, 1, 3, 5, etc.

SEVEN-CYLINDER ENGINES.

A séven-cylinder engine which has proved very successful, and was used on two of the Farman and one of the Voisin machines at the Rheims meeting, is the "Gnome" (Fig. 5). A peculiarity of this engine is that the cylinders and crank-case revolve round a *fixed* crank-shaft, from which the pistons get a push-off. Their rapid motion through the air cools the cylinders sufficiently without the aid of water circulation—which would be difficult to arrange on a rotary engine—and renders a fly-wheel unnecessary. This last feature means a considerable saving of weight. In this engine

Fig. 6.—THE SEVEN PISTON RODS AND COMMON "BIG-END" OF A "GNOME" ENGINE.

One of the seven rods is integral with the big-end. The other six work on pins passing through it.

no aluminium is used, and most of the parts are of nickel steel forged by hand.

The stationary and hollow crank-shaft is attached rigidly to the frame of the flying machine, the cylinders and crank-case to the propeller itself—a position which gives the most efficient cooling—or to the propeller shaft. If circumstances demand, the engine can be mounted with its axis vertical, to drive the propeller shaft through bevel gearing.

All seven connecting rods work on a single crank. One of the seven, the "master," carries a double-disc big-end, pierced with six pairs of holes to accommodate the six pins for the rods (see Fig. 6). The big-end itself is separated from the crank by ball bearings.

The 50 horse-power engine, with cylinders of 120 mm. stroke and 110 mm. bore, weighs but 160 lbs., or but little more than 3 lbs. to the horse-power.

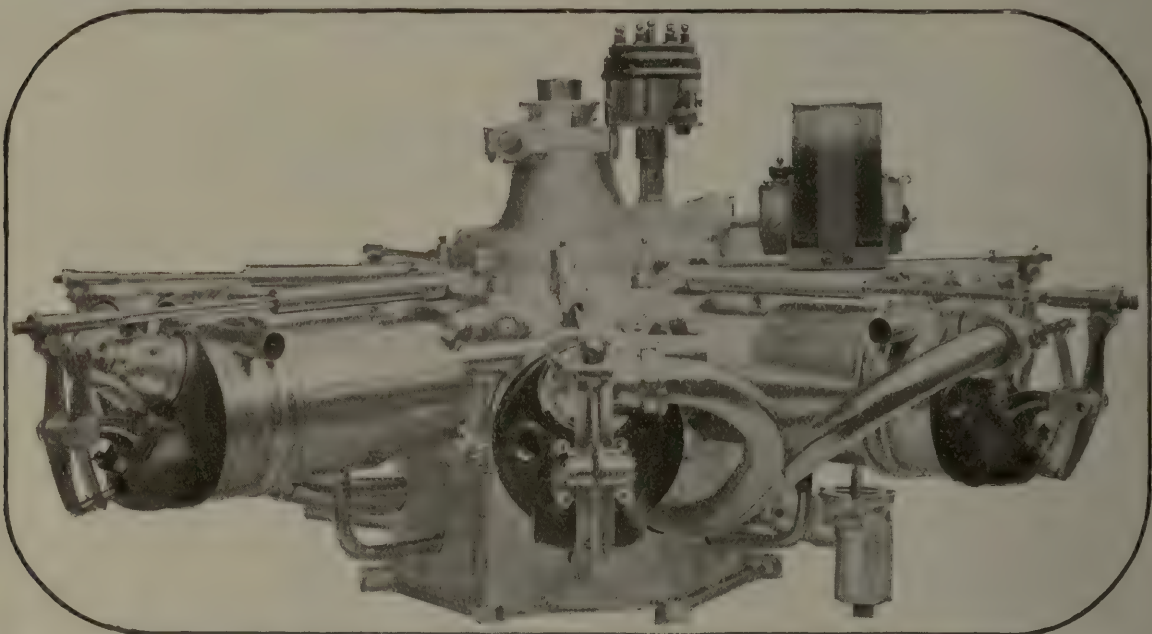


Fig. 7.—THE "BAYARD-CLÉMENT" 55 HORSE-POWER SEVEN-CYLINDER ENGINE. WEIGHT, 155 LBS.
The cylinders are stationary, but no fly-wheel is needed. (*Photo, Topical.*)

The explosive mixture is drawn by the movements of the pistons through the crank-shaft into the crank-case, whence it finds its way into the cylinders through automatic inlet valves situated in the piston heads. These valves are counterbalanced, so as not to be affected by the centrifugal force of rotation; the same remark applies to the exhaust valves on the cylinder heads, operated by rods and rocking levers from cams rotated by epicyclic gearing at the end of the crank-case. The magneto and a pump for circulating lubricating oil are mounted on the shaft, and do not revolve with the engine.

The Bayard-Clément Engine.

The Bayard-Clément seven-cylinder engine (Fig. 7) differs from the "Gnome" in that the cylinders are stationary and the crank revolves. The exhaust and inlet valves of each cylinder, situated on the head, are operated by a single rocking lever. A small pump, mounted in the crank-case on the crank-shaft, drives water through jackets surrounding the cylinders. The carburettor, outside the case, is connected by a single pipe to a chamber inside the case adjacent to the pump. From this chamber pipes run through the walls of the case to the seven inlet valves.

At the opposite end of the case is the cam which works all seven valve-tappet rods. The distributor is driven by a half-speed shaft, and the magneto by a cross-shaft and bevel gearing.

The engine is mounted with its shaft vertical, as shown in Fig. 7. A bevel gearing is therefore needed to impart motion to the horizontal propeller shaft. Cylinders, bore 110 mm., stroke 92 mm.; power developed, 55 horse-power; weight, about 155 lbs. No fly-wheel is used, as the explosions, occurring at regular intervals, give the crank a constant torque.

The "R.E.P." Engine.

The "R.E.P." (Robert Esnault-Pelterie), the first successful seven-cylinder engine, has all the cylinders mounted on the upper half of the crank-case, four being in one plane and three in another. The crank has two throws, operated by four and three pistons respectively, the piston rods of each group being attached to a single big-end. Extremely light pistons are used, and to save weight the bearings for the gudgeon pin of the piston rod are made part of a piece which screws into the socket in the centre of the piston head, and is secured by a screw. A peculiar feature of this engine is that one valve passage serves for both inlet and exhaust. The inlet valve is of the ordinary mushroom-headed type. The exhaust valve has the form of a cylindrical collar surrounding the inlet valve stem, and moving up and down in a cage, the walls of which are perforated. When the collar uncovers the ports, the cylinder is put into communication with the exhaust pipe. The seven-cylinder "R.E.P." weighs 115 lbs. and develops 30 horse-power. A ten-cylinder engine with two sets of five cylinders, mounted in four planes on top of the crank case, is made. It develops 40–50 horse-power. The cylinders of these motors are provided with external fins, and are cooled by air draught.

This section may end with reference to the Adams Farwell five-cylinder revolving air-cooled engine. Like the Bayard-Clément, it runs round a vertical crank-shaft. The 36 horse-power size is remarkably light—only 97 lbs. The 63 horse-power type weighs 4 lbs. per horse-power. Centrifugal force is used instead of the usual coiled springs to close the valves.

EIGHT-CYLINDER ENGINES.

The first extremely light aeroplane engine put on the market was the Antoinette, which has won a high reputation for itself. The air-cooled type scales only about 2½ lbs., the water-cooled about 5 lbs., per horse-power. The cylinders, of forged steel, are grouped in two sets of four, mounted at right angles to one another on the top of an aluminium crank-case. Two pistons operate each of the four throws of the crank-shaft. The cam-shaft for working the eight exhaust valves is situated inside the case over the crank-shaft. By moving this shaft slightly end-ways the engine can be reversed. The inlet valves are automatic.

The Antoinette.

Where water cooling is used, a thin copper dome-topped jacket surrounds the cylinder and the guide of the exhaust valve stem. At the bottom the jacket is soldered to an external ring on the cylinder.

Lubricating oil is forced by a small pump into a tube running along the inside of the top of the crank-case, and squirted in all directions through a number of tiny holes on to the crank and cam-shafts, pistons, rods, and cylinder walls. Carburation is produced by a little petrol pump driven by the engine, which delivers petrol into eight little distributors placed near the inlet valves. The distributors store the petrol during the three non-suction strokes. When the inlet valve opens the petrol is drawn into the cylinder, being pulverized and vaporized during the process. The supply is regulated by altering the stroke of the pump's plunger. This system avoids

the use of long induction pipes, and saves a few pounds of weight.

Engines of the eight-cylinder V class include that manufactured by the Wolseley Tool

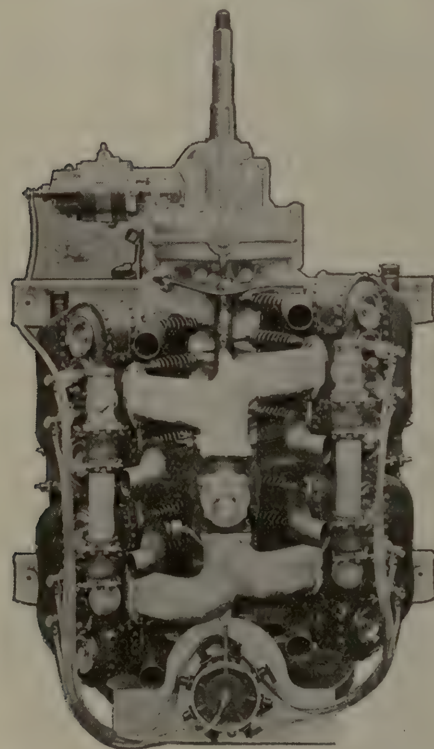


Fig. 8.—THE WOLSELEY EIGHT-CYLINDER 60 HORSE-POWER ENGINE. WEIGHT, 340 LBS.
In this type the propeller is driven off the cam-shaft at half-engine speed.

and Motor Car Company (Figs. 8 and 9). This firm's engine has cylinders of 3¾-inch bore and 5-inch stroke. All the valves are operated mechanically by a central cam-shaft and rockers. The cylinders, of close-grained cast-iron, are cast in pairs, and each pair is surrounded by a water-jacket shaped out of planished sheet aluminium. Water circulation through the jackets is on the thermo-syphon principle, which does not require a pump.

The Wolseley Engine.

A float feed and spray type carburettor is mounted in the centre of the engine directly over the cam-shaft—an arrangement which allows of short induction pipes, and ensures an equal distribution of explosive mixture to the cylinders. The weight of the engine, complete with fly-wheel, ignition, water-pipes, and exhaust pipes, is 340 lbs.; the power developed at 1,350 revolutions per minute is 50 B.H.P.; and the maximum obtainable 60 B.H.P. This gives an average of about 6 lbs. per horse-power. For aeroplane work the engine may be arranged to drive the propellers direct from the crank-shaft, or, by means of gearing, at cam-shaft speed. For large propellers the second method is preferable.

The Fiat, Jap, Pipe, and Renault are all air-cooled, but differ considerably in detail. The Fiat (Fig. 10) is enclosed in a circular case, through which a strong current of air is driven by a fan. The combustion heads are detachable for cleaning the inside of the cylinders. The engine develops about 40 horse-power, and weighs 135 lbs.

Other Eight-Cylinder V Engines.

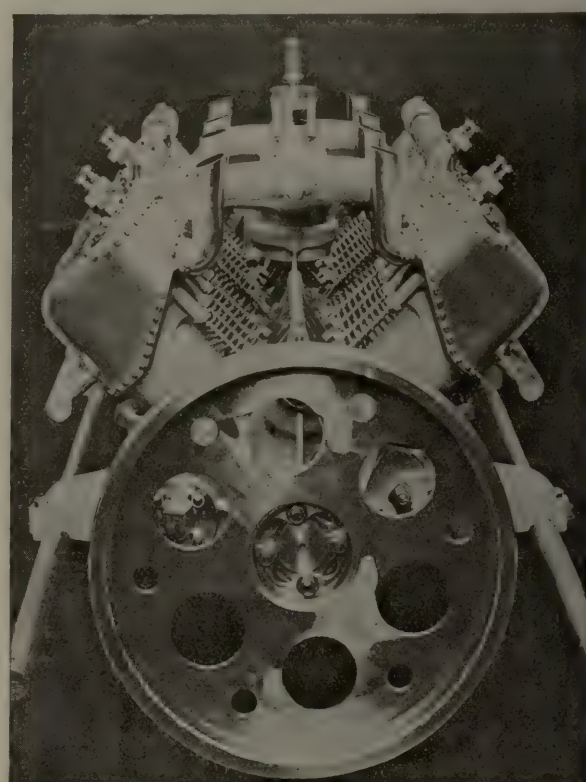


Fig. 9.—WOLSELEY ENGINE, DIRECT DRIVE TYPE. END VIEW.

The English-built Jap engine has a bore of 85 mm. and a stroke of 95 mm., and develops 30–35 horse-power at 1,000 revolutions per minute, and weighs about $5\frac{1}{2}$ lbs. to the horse-power. The 70 horse-power Pipe engine (Fig. 11) weighs 280 lbs., and has cylinders of 100 mm. bore and 100 mm. stroke. It works at very high speeds—up to 2,000 revolutions per minute. The cylinders, furnished with longitudinal cooling ribs, are covered by light aluminium jackets, through which air is forced by a centrifugal pump mounted on the crank-shaft. Another interesting feature is that the valves of each cylinder are concentric, and operated by pairs of overhead rockers, one of which is forked so as to allow the point of the other to move through it.

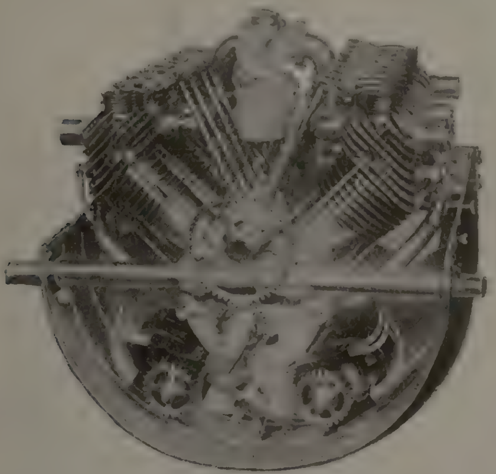


Fig. 10.—"FIAT" EIGHT-CYLINDER 40 HORSE-POWER AIR-COOLED ENGINE. WEIGHT, 135 LBS.

(*Photo, Topical.*)

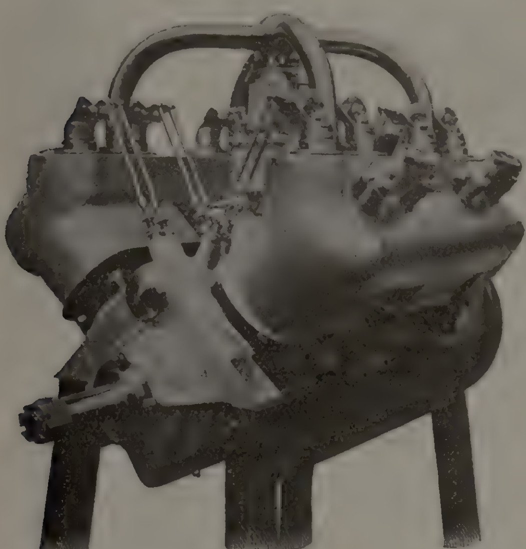


Fig. 11.—EIGHT-CYLINDER 70 HORSE-POWER "PIPE" AIR-COOLED ENGINE. WEIGHT, 280 LBS.

The cylinders are enclosed in jackets, through which air is forced by a fan.

(*Photo, Topical.*)

The Gobron.

The Gobron engine (Fig. 12) is very distinctive both externally and internally. The eight cylinders are arranged in four pairs to form a cross. In each cylinder are two pistons working in opposite directions. When an explosion occurs the pistons are forced apart, one moving towards, the other away from, the crank-shaft. The eight inner pistons have the usual connecting rods to the crank; the outer pistons of a pair of cylinders are connected to a common cross-beam from which long connecting rods run outside the cylinders to separate cranks, set in line at an angle of 180° to the central crank.

Fig. 12.—EIGHT-CYLINDER CROSS-SHAPED "GOBRON" ENGINE.

The 80 horse-power type weighs 440 lbs.

(*Photo, Topical.*)

THE CRANKS AND CRANK-CASE OF ONE OF THE 220 HORSE-POWER ENGINES BUILT FOR "CLÉMENT-BAYARD II."

(*Photo, Illustrations Bureau.*)

THE CONSTRUCTION OF AEROPLANES AND AERIAL PROPELLERS.

APART from the engine, propeller, and under-carriage, the aeroplane may appear to the uninitiated to be an apparatus that could easily be constructed by any person "clever with his hands." The decks are merely wooden frames covered on one or both sides by fabric, the spars and outriggers nothing but easily-shaped pieces of wood. Such staying with cross wires as is necessary looks a simple enough job. In short, the building of an ordinary pleasure boat would seem to be a much more difficult business for any one who had never tried his hand on it before.

A closer examination of the matter shows, however, that the aeroplane is not so simple a structure as a first view might lead one to think. The designer has constantly to wrestle with an arch enemy, weight, which will sneak its way in if given half a chance; and in keeping it at bay, he must be careful not to open the door to weakness. Then, too, he has to beware of exposing an undue amount of resisting—as distinguished from lifting—surface to the air, lest he should waste the power of his engine in useless work.

To begin with the materials used. Bamboo is commonly considered to be extraordinarily strong for its weight. As a matter of fact, it is in this respect decidedly inferior to many other woods; while its hollowness, and the impossibility of shaping it to any required section, restrict its usefulness considerably. A table of relative strengths shows that Honduras mahogany is, weight for weight, two and a half times as tough as bamboo; lancewood, twice; spruce, one and a half times; ash, one and a third times.

Woods used.

As the chassis of a motor car is built entirely of metal, but different metals are used for different purposes, so in the wooden framework of an aeroplane we find different kinds of wood selected for special duties. Upright stanchions between decks may be of ash; the main spars of spruce; the ribs of ash, hickory, or poplar—woods which can easily be bent to the proper curves. For the main spars of a deck, spruce is most commonly used when it can be obtained in sufficient lengths, and is free from knots and "shakes." To the spars are attached the ribs, which are steamed and bent to shape on wooden templates. The number of spars varies according to the type of machine. Biplane decks usually have two only. A monoplane deck, having to rely on itself for stiffness, as the girder form of construction is not available with a single tier of decks, may possess several auxiliary spars, in addition to the two main ones. These last, in the case of the Blériot short-span monoplane, have projecting ends which fit into sockets in the body of the machine, to render the wings easily detachable for transport.

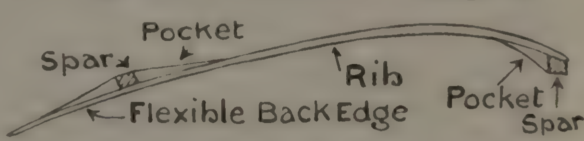


Fig. 1.—A SINGLE-SURFACED DECK, SHOWING POCKETS COVERING SPARS.

Decks.

Decks are either single or double-surfaced. The first type (see Fig. 1) has the ribs attached to the top of the front spar and to the under side of the rear spar. The fabric—cotton cloth or silk impregnated with rubber or faced with cellu-

AT WORK IN AN AEROPLANE FACTORY.

loid—is fastened to the under side of the ribs, and the rear spar and the ribs are enclosed in pockets of the same material, so that no surfaces may be opposed squarely to the passage of the air. This method of construction is economical in fabric, but the attachment of the pockets is a somewhat troublesome business.

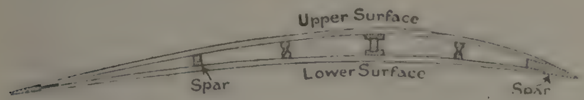


Fig. 2.—A DOUBLE-SURFACED DECK, SHOWING SPARS AND BLOCKS SEPARATING UPPER AND LOWER RIBS.

For double-surfaced decks (see Fig. 2) the spars, other than the front one, are enclosed by the ribs and fabric. This form of deck gives a better "run" for the air over the upper side, which is much more free from excrescences than the single-surfaced deck, and is therefore more efficient.

The fabric must be stretched as tightly as possible over the framework to prevent undue sagging under pressure of the air. At the trailing edge of the deck it is commonly passed round a taut cable running longitudinally from end to end, or round a fine spar.

The upright stanchions between the decks of a biplane are of oval or fish-shaped sections, and arranged with their greatest diameter fore and aft. These and the decks are braced together diagonally with piano wires or fine cables drawn tight, and provided with adjustments for taking up any slack. It is important that the wires should not be able to vibrate, since a vibrating wire offers more resistance to the air than one that remains quite taut. The girder formed by the deck spars and the stanchions is, if properly designed, very strong. To test a certain glider, weighing only about 150 lbs., and having a 30-foot span, the ends of the decks were supported on stools, and a 14-stone passenger took his seat at the centre. The deflection was only half an inch.

Body Work.

Outriggers and the body work of a machine are also built up on the girder principle, so as to be able to withstand sudden and violent strains. A monoplane body is given a more or less decided torpedo or boat shape, tapering somewhat abruptly towards the front and gradually towards the tail, as shown by our illustrations of the Blériot and Antoinette machines. The covering-in of the body with tightly stretched fabric helps to lessen its resistance to the air.

The Chassis.

A very important part of an aeroplane is the chassis, or wheeled carriage, which supports most of the weight while the machine is at rest, and enables it to run easily over the ground when getting up speed for a start. In the chassis steel tubing is employed, as wood could not be relied upon to resist the sudden shocks caused by alighting. Two or more wheels, shod with pneumatic tyres, are generally placed under the main decks, and one or two under the tail where a horizontal tail is fitted. Cody and Curtiss use three in front, Farman four, and Voisin two. Voisin and Blériot mount their wheels castor fashion, so as to adjust themselves automatically to the direction which the aeroplane may take, and interpose springs to minimize shocks to the body of the machine. Special springs are provided to bring the wheels into a fore and aft position when the aeroplane rises from the ground.

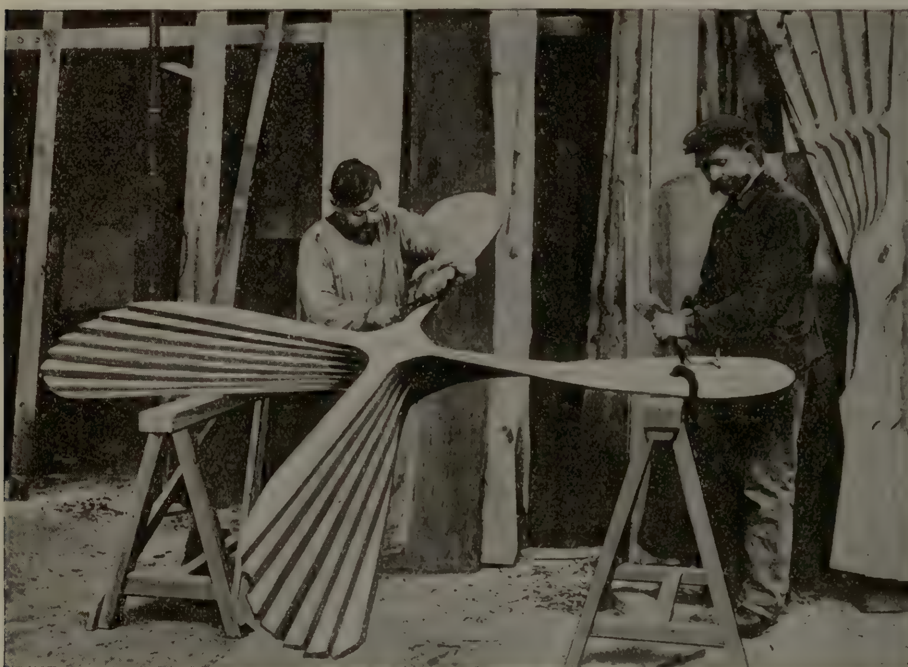
The Wrights, by dispensing with a wheeled chassis, reduced the total weight of their biplane and also its air resistance considerably. The Voisin chassis accounts for 250 lbs., or half as much again as the main decks.

SCREW PROPELLERS.

Good design of aeroplanes and high engine power in proportion to weight are of little avail, if the means of converting the engine power into work are inefficient. Locomotives driven over rails and roads are enabled to transmit their force from the moving

body to the fixed surface without appreciable loss. But in water and air, which can be displaced easily, the problem of getting, so to speak, a good push-off is one that has demanded close investigation and a huge amount of experiment.

For moving a ship or a flying machine the screw propeller has no rival. The marine propeller has been brought to great perfection; air propellers are being improved rapidly, but are still, as a class, wasteful of power.



CONSTRUCTING A FOUR-BLADED PROPELLER OUT OF SUPERIMPOSED LAMINÆ OF WOOD. (*Photo, London Electrotype Agency.*)

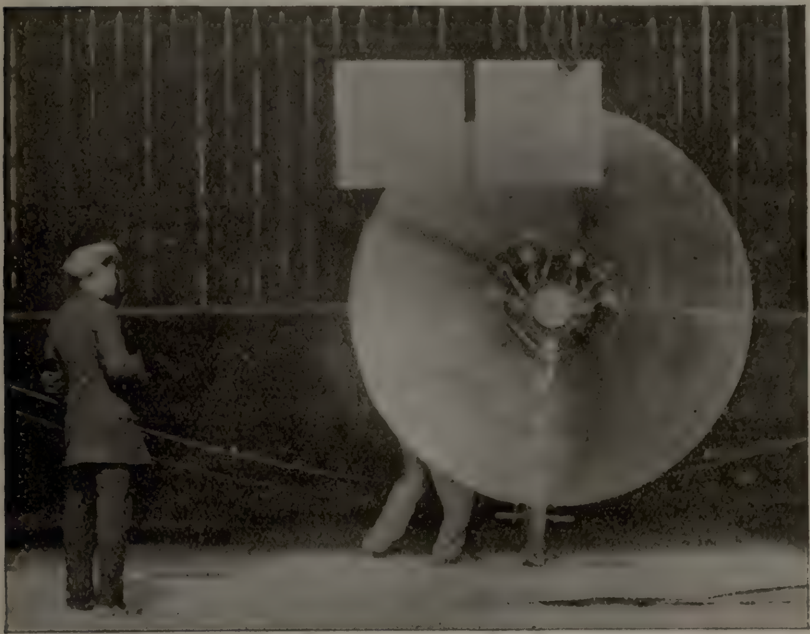
The air propeller is in principle closely allied to the curved deck of the aeroplane. As it revolves it strikes the air at an angle, and produces *thrust*, which is the counterpart of the lift of a deck. Owing to the fact that the speed of the parts of a propeller blade vary with their distance from the centre of rotation, it is necessary to increase the steepness of the angle of the blade gradually from the tip to the base in such a way that the increase of angle may counterbalance the decrease in rotary speed, and enable all parts of the blade's surface to push back the air with an equal velocity. Otherwise, there would be a great waste of power, some portions of the blade acting as a drag on the others.

A propeller blade would, if flattened and set square to the axis of the propeller shaft, offer a minimum turning resistance; if set with its surfaces in line with the shaft, a maximum resistance. In neither case would it have any lift or thrust. The designer has to consider how to curve the blades so as to give a maximum thrust for a minimum windage, which is the counterpart of drift, and at the same time he must be careful to make the surfaces as smooth as possible in order to keep air-friction very low.

The efficiency of a screw is gauged by the amount of thrust which it gives in proportion to the force exerted to turn it. The thrust itself is arrived at by multiplying the weight of the mass of air acted on in a second by the velocity in feet per second at which that mass of air is moved. The amount of air engaged varies —the pitch being constant—as the square of the diameter of the propeller. The velocity in feet per second at which it is moved is the pitch multiplied by the number of revolutions per second.

Thrust.

Assuming that the screw is perfectly effi-



A PROPELLER WHIRLING AT HIGH SPEED. *(Photo, Illustrations Bureau.)*

cient, the full thrust for power may be obtained either by using a small screw revolving at engine speed, or a larger screw turning at less than engine speed. In the first case the mass of air is less than in the second case, but the velocity imparted to it is greater; in the second, the mass is larger but the velocity less. The essential point is to proportion and gear the propeller so that the engine shall be able to run at its most efficient speed.

So far the imparting of motion to air by a fixed propeller has been considered. To obtain the rate of progression in feet per minute at which a machine would be driven by the propeller through the air one must multiply the pitch of the propeller in feet by the number of revolutions per minute, and deduct the "slip"—that is, the velocity of the air flung back by the propeller. A propeller with a 5-foot pitch revolving four hundred times per minute would have a "designed" forward speed of 2,000 feet per minute. If the air left it at 500 feet per minute, the actual speed of the machine would be 1,500 feet per minute. High velocity of slip is not necessarily a test of thrust, as it depends largely on the resistance of the machine to the air.

Slip.

In practice it is found that a large propeller turning at comparatively low speeds gives a greater thrust than a smaller propeller driven at very high speed, the power exerted being the same in both cases, and the pitch proportioned to give the requisite flight speed necessary to support the aeroplane. For this reason the Wrights use two large slow-speed propellers, to which is due, in no small degree, the high efficiency of their machines proportionately to the horse-power of the motors employed. Convenience of attachment is a point in favour of the direct driven propeller, found on most monoplanes and many biplanes. There is a growing tendency, however, to increase the size of the propeller where convenient. We may note, by way of example, that Blériot now uses geared-down screws of large diameter for his heaviest monoplanes.

The highest efficiency obtained so far by an aerial propeller does not exceed probably 70 per cent. It is anticipated that this may be improved upon until 85 to 90 per cent. of the engine power is usefully applied. This will make possible a considerable reduction in weight of engine, which in turn will lead to a diminution in the size of aeroplanes.

Construction of Propellers.

Propellers are made of steel, aluminium, magnalium, and various kinds of wood. On the whole, the wooden propeller appears to be most satisfactory. It can be made exceedingly light without sacrificing strength,

keeps its shape well under heavy pressure, and admits a surface polish which reduces skin friction practically to vanishing point. The woods selected for its manufacture are walnut and spruce. The last is very light, easily shaped, and tough.

AVIATION RECORDS.

Date.	Aviator.	Place.	Type of Machine.	Duration of Flight.	Distance, etc.
1897. Oct. 17.	Ader.	Satory, France.	Monoplane.	......	1,000 ft.
1903. Dec. 17.	Orville and Wilbur Wright.	Dayton, U.S.A.	Biplane.	59 secs.	......
1905. Sept. 26.	,,	,,	,,	18 min. 9 sec.	11 miles.
,, 29.	,,	,,	,,	19 min. 55 sec.	12 miles.
Oct. 3.	,,	,,	,,	25 min. 5 sec.	15½ miles.
,, 4.	,,	,,	,,	33 min. 17 sec.	21 miles.
,, 5.	,,	,,	,,	38 min. 3 sec.	24½ miles.
1906. Aug. 22.	A. Santos Dumont.	Bagatelle, France.	,,	Rose from the ground.	First public flight.
Sept. 14.	,,	,,	,,	A few seconds.	......
Oct. 24.	,,	,,	,,	4 sec.	160 ft.
Nov. 13.	,,	,,	,,	7 sec.	270 ft.
,, 13.	,,	,,	,,	21⅕ sec.	722 ft.
1907. Oct. 15.	H. Farman.	Issy, France.	,,	21 sec.	937 ft.
,, 26.	,,	,,	,,	27 sec.	1,267 ft.
,, 26.	,,	,,	,,	31⅗ sec.	1,322 ft.
,, 26.	,,	,,	,,	52⅗ sec.	2,529 ft.
1908. Jan. 13.	,,	,,	,,	1 min. 28 sec.	1,093 yards. (First circular flight.)
Mar. 21.	,,	,,	,,	3 min. 31 sec.	1·24 miles.
April 11.	L. Delagrange.	,,	,,	6 min. 30 sec.	2·43 miles.
May 30.	,,	Rome.	,,	15 min. 26 sec.	7·88 miles.
,, 30.	H. Farman.	Ghent, Belgium.	,,	......	1,360 yards. With E. Archdeacon as passenger; first public passenger flight.
July 6.	,,	Issy, France.	,,	20 min. 19⅘ sec.	12·66 miles.
Sept. 6.	L. Delagrange.	,,	,,	29 min. 53⅘ sec.	14·23 miles.
,, 9.	Orville Wright.	Fort Myer, U.S.A.	,,	57 min. 31 sec.	......
,, 10.	,,	,,	,,	1 hr. 5 min. 52 sec.	......
,, 11.	,,	,,	,,	1 hr. 10 min. 24 sec.	......
,, 12.	,,	,,	,,	1 hr. 14 min. 20 sec.	......
,, 12.	,,	,,	,,	9 min. 6 sec.	With Major Squier; record passenger flight.
,, 21.	Wilbur Wright.	Le Mans, France.	,,	1 hr. 31 min. 25⅘ sec.	41 miles.
,, 25.	,,	,,	,,	11 min. 35 sec.	With passenger.
Oct. 3.	,,	,,	,,	55 min. 37⅘ sec.	,,
,, 6.	,,	,,	,,	1 hr. 4 min. 26⅕ sec.	,,
,, 10.	,,	,,	,,	1 hr. 9 min. 45⅘ sec.	34·2 miles. With passenger.
,, 30.	H. Farman.	Châlons, France.	,,	20 mins.	16·5 miles. First cross-country flight. Châlons to Rheims.
,, 31.	L. Blériot.	Toury, France.	Monoplane.	......	17·5 miles. First cross-country flight, with return to starting-point; Toury to Artenay and back; two landings on the way.
Dec. 18.	Wilbur Wright.	Le Mans, France.	Biplane.	1 hr. 54 min. 53⅖ sec.	62 miles.
,, 31.	,,	,,	,,	2 hr. 20 min. 23⅕ sec.	77½ miles.
1909. July 25.	L. Blériot.	Calais to Dover.	Monoplane.	37 min.	30 miles.
Aug. 7.	R. Sommer.	Châlons, France.	Biplane.	2 hr. 27 min. 15 sec.	......
,, 25.	L. Paulhan.	Rheims, France.	,,	2 hr. 43 min. 24⅘ sec.	82 miles.
,, 26.	H. Latham.	,,	Monoplane.	2 hr. 17 min. 21⅗ sec.	96½ miles.
,, 27.	H. Farman.	,,	Biplane.	3 hr. 4 min. 56⅖ sec.	112 miles.
,, 29.	,,	,,	,,	10 min. 39 sec.	6·21 miles. First flight with two passengers.
Sept. 8.	S. F. Cody.	Aldershot.	,,	1 hr. 3 min.	46 miles. First cross-country flight in England.
,, 17.	Orville Wright.	Berlin.	,,	Attained altitude of	607 feet.
,, 18.	,,	,,	,,	1 hr. 35 min. 47 sec.	Record with passenger.
,, 19.	H. Rougier.	Brescia.	,,	Attained altitude of	650 feet.
,, 30.	O. Wright.	Berlin.	,,	Attained altitude of	902 feet.

For Records of Dirigible Balloons see page 64.

DIRIGIBLE BALLOONS.

IN the minds of a good many persons there undoubtedly exists a confusion as regards the terms "airships" and "flying machines." That this should be so is somewhat curious, as a little thought must make it evident that a "ship" implies something that floats by virtue of its own buoyancy in the medium through which it moves; and the term airship, therefore, must apply only to the dirigible balloon. On the other hand, every living thing that *flies* is heavier than air, and supports itself only by the action of moving parts on the air. Hence the words "flying machine" obviously refer to contrivances which lift as well as propel themselves by the development of power. The airship has its counterpart in the submarine boat; the flying machine may be compared to the hydroplane, which is supported when moving at high speed by the resistance to water of more or less oblique horizontal surfaces, and not by buoyancy.

Terminology.

If the atmosphere surrounding our globe were untroubled by currents, the dirigible balloon would have "arrived" many years ago. To make a cigar-shaped envelope, attach thereto a car, and provide motive power of some kind would not have presented very serious difficulties; and the improvement of motors would have greatly increased the, at first, unavoidably low speeds. Unfortunately, from the point of view of the "dirigible," the air ocean has a constant motion, at times almost imperceptible, at others terrifying in its velocity. Even the more gentle of the intermediate strengths of current have to be reckoned with.

The resistance of the air to a large body moving through it demands that the shape of a dirigible should be considered carefully. A sphere has greater volume than a body of any other shape proportionately to its surface. But to drive a sphere through the atmosphere requires half the power needed to propel a circular plane of equal diameter flatways on; and therefore a spherical form is evidently not suited for a "dirigible." On the other hand, the more or less cigar-shaped form adopted, though offering less resistance, has an envelope that is heavy relatively to the volume of gas imprisoned. Its efficiency is, however, augmented by a general increase in dimensions—the proportions being constant—as the doubling of surface area of the envelope far more than doubles the cubical contents.

Shape of Airships.

To consider for a moment the shape. Experiment has shown that a hemispherical

THE "COLONEL RENARD" AT RHEIMS. *(Photo, Illustrations Bureau.)*

This is one of the smaller French non-rigid dirigibles, with stabilizing ballonets at the stern.

THE MALÉCOT SEMI-RIGID AIRSHIP. (*Photo, Bolak.*)

To the balloon are attached a number of planes, which can be set at an angle to the horizontal to give vertical motion. In case of the collapse of the gas-holder, they would also have some of the effect of a parachute.

prow and a conical tail give the best results as regards minimizing resistance. It is much less important to avoid a blunt prow than to keep the lines of the after-part fine, since the resistance of the air to being pushed aside is small as compared with the "suck" of a badly-shaped stern. The ideal form has been adopted for a recently built Italian airship, and, with modification, for most other dirigibles. German examples—the Zeppelins excluded—have the hemispherical prow and conical tail, but these are separated by a cylindrical body. Some French airships have a conical prow. The Zeppelins are distinguished by a very long cylindrical body, terminated at both ends by what may be termed a spherical cone. In this type the head resistance is said to be about one-fifth of that of a circular plane of the same area as the cross-section of the body. In practice the shape of the envelope is governed by several factors other than that of mere resistance, and is more or less of a compromise. In a paper on military aeronautics, Major G. O. Squier, of the United States Army Signal Corps, laid it down that the power consumed in propelling a displacement vessel supported by air or water at any constant speed is considered as being two-thirds consumed by skin-resistance or surface resistance, and one-third by head resistance; and that a dirigible balloon carrying the same weight, other things being equal, may be made to travel about twice as fast as a boat for the same power, or to be made to

Prows and Sterns.

Resistances.

travel at the same speed with the expenditure of about one-eighth of the power. "As there are practically always currents in the air reaching at times a velocity of many miles per hour, a dirigible balloon should be constructed with sufficient power to be able to travel at a speed of about 50 miles per hour, in order that it may be available under practical conditions of weather. In other words, it should have substantially as much power as would drive a boat, carrying the same weight, 25 miles an hour, or should have the same ratio of power to size as the *Lusitania*."

Pressure on the Envelope.

The pressure on the envelope of a balloon, when the latter is moving at high velocity relatively to the air, must indent it and cause great increase of resistance unless the envelope be either kept taut by inflation or supported by a rigid framework of some kind. As high inflation is prevented by the comparative weakness of the fabric, and even, if feasible, would mean a sufficient compression of the gas to cause a serious loss of buoyancy, the "rigid" school, whose great exponent is, of course, Count von Zeppelin, makes use of an internal skeleton, a light polygonal girder running from stem to stern. The weight of the girder makes great volume necessary, and to obtain this without increasing the head resistance unduly, the body is given a length of rather more than ten diameters. A single container of this shape would be subjected to dangerous surgings of gas to and fro as either end rose and fell, so Zeppelin has adopted a number of small balloons separated from one another by partitions, and from the external covering of the balloon by an air-space which serves to insulate the gas from the changes in temperature of the atmosphere. This subdivision has the further advantage of localizing damage to the balloon. Had the ill-fated *République* not had a single chamber, she might have come to ground without fatal results.

Zeppelin Principle.

Ballonets.

For non-rigid dirigibles one or more internal air ballonets are used. Air is pumped constantly into them, escaping again through a valve if the pressure rises above a certain point. The gas chamber also is provided with a valve, acting at a somewhat higher pressure, so that under no conditions can the distension of the ballonets cause a loss of gas. If the gas is expanded by a rise in temperature, the ballonet is squeezed until the pressure is normal. If, on the other hand, the gas contracts or leaks, the ballonet swells out until equilibrium is restored.

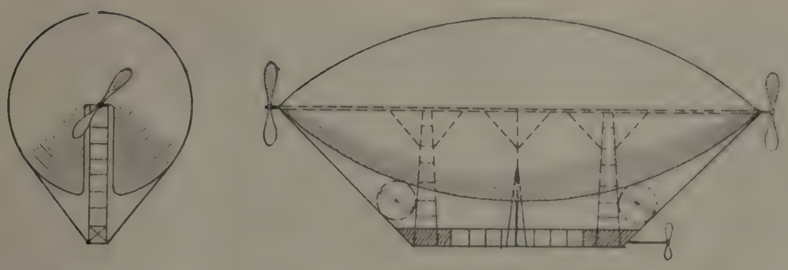
Distribution of the Load.

The distribution of the load over the gas holder in such a way as not to strain any part unduly is, in the case of a Zeppelin airship, simplified by the employment of a girder keel. Unless the distribution is made properly over a non-rigid envelope, there must be a danger of the balloon collapsing. To simplify the problem a keel or frame fitting the lower side of the envelope is used, and from it are slung the car, motor, etc. Dirigibles thus provided are known as *semi-rigid*, and have some of the stiffness of the Zeppelin type, while being capable of deflation like the non-rigid type, though less convenient for transport by land. The German *Gross* and the French *Lebaudy* and *République* belong to this class.

Application of Power.

The rigid airship has a further advantage over the non-rigid in that the propellers can be attached to the gas-holder frame and deliver their thrust at the same elevation as that of the centre of air pressure. In the case of a non-rigid or semi-rigid airship, the propellers are mounted far below the centre of pressure, and this produces a tilting action and less efficient drive.

Renard, during his experiments in 1884 and 1885, found that his airship began to pitch—tilt up and down longitudinally—as



SEVERO'S DIRIGIBLE BALLOON (1902):

The propeller shaft was mounted at the axis of the balloon to give a direct thrust. Two small propellers at the ends of the car were used for lateral steering; a single propeller at the stern for vertical steering.

soon as it attained a certain speed. To obviate this tendency he attached horizontal, fin-

Stability.

like planes to the tail, a practice which has been followed in more recent designs. The French *Ville de Paris* and *Clément-Bayard* have, instead of planes, small ballonets, cylindrical in the first case, pear-shaped in the second. (See the illustrations on pages 58 and 57 respectively.) Pitching arises from irregularities in pressure and the presence of ascending or descending air currents, from the leakage of gas, and the shifting of the dead or the live load. The lower the centre of gravity is kept the less will the pitching be. Movable weights for correcting the trim are used. On the Gross airship two ballonets—one forward and the other aft—are connected by a pipe through which air is transferred from one to the other to alter the buoyancy of either end. As Moedebeck remarks in his *Handbook of Aeronautics*, the maintenance of stability in long airships is one of the most difficult problems for the constructor.

Vertical steering is effected by the aid of planes attached to the balloon or the body, and by altering the longitudinal trim. The

Steering.

Zeppelin airships carry sets of planes fore and aft, which, if set at an angle of 15° to the horizontal, will at 31 miles an hour give a lifting force of nearly a ton, and enable a rapid ascent to be made without throwing away ballast. The French *Malécot* (see page 47) has under the envelope a number of aeroplanes, upon which devolves part of the duty of raising the airship from the ground and keeping it aloft. This particular airship is, in fact, not a true "ship," as it does not float by its own buoyancy. For lateral steering one or more vertical rudders placed near the stern are used.

DEVELOPMENT OF THE AIRSHIP.

The first airship to attain an independent velocity was that built by Henry Giffard, the inventor of the famous water injector now commonly used for steam boilers, in 1852. (Fig. 1.) It was about 136 feet long and

Giffard's Dirigible.

37 feet in diameter, and had a capacity of 2,000 cubic metres. Its weight was 2,794 lbs., its lifting capacity 1¾ tons. The 3 horse-power steam-engine used to drive it weighed 462 lbs.—a striking contrast to the light but extremely powerful petrol engine of to-day. The car, containing the engine, was suspended from a horizontal rod to which the cordage of the envelope was attached. On September 24, Giffard made an ascent at Paris, and succeeded in obtaining a speed estimated variously at 4½ and 6¾ miles an hour.

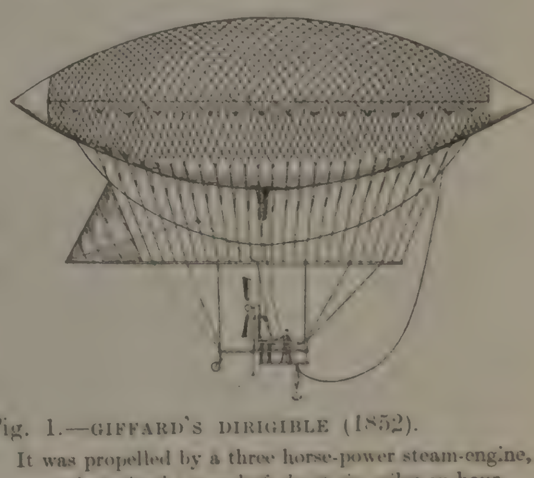
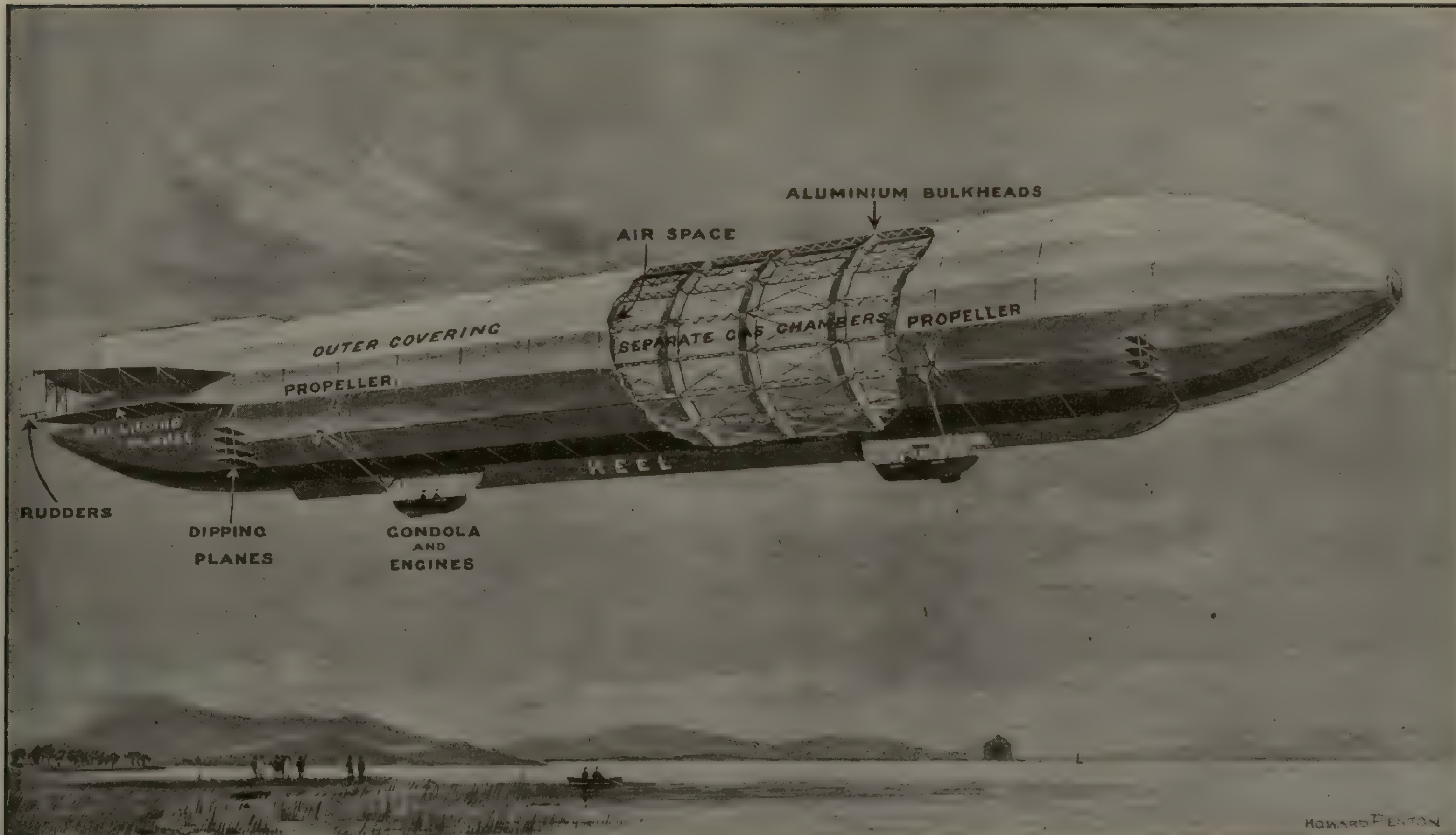


Fig. 1.—GIFFARD'S DIRIGIBLE (1852).

It was propelled by a three horse-power steam-engine, and attained a speed of about six miles an hour.



VIEW OF ZEPPELIN DIRIGIBLE, WITH PART OF EXTERNAL COVERING REMOVED TO SHOW THE SEPARATE GAS CHAMBERS AND LATTICE GIRDERS OF THE FRAME.

The latest patterns have seventeen chambers, and measure 453 feet from bow to stern. Their volume is 15,000 cubic metres.

During the siege of Paris (1870) Dupuy de Lôme built for the French Government a dirigible shaped somewhat similarly to that of Giffard. In place of an engine the muscles of eight men were employed to turn a large screw, nearly 30 feet in diameter, about twenty-eight times per minute. The airship moved itself at a low speed, but apparently the inventor and the Government did not consider its behaviour sufficiently satisfactory to justify sending it over the beleaguering German army.

Dupuy de Lôme.

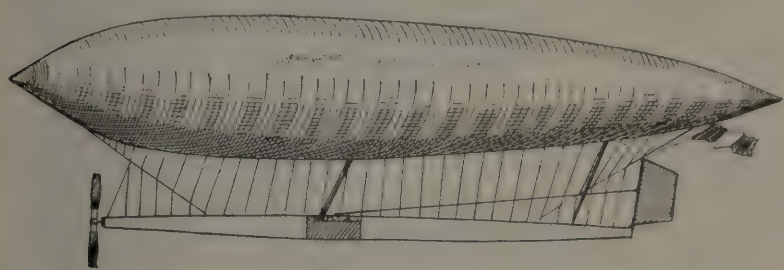


Fig. 2.—RENARD AND KREBS' AIRSHIP (1884).

The first really successful navigable balloon. Propelled by electric motors. It made several considerable voyages at a good speed. Highest velocity attained, about fourteen miles an hour.

Passing over the experiments of Haenlein and Tissandier, we come to the famous airship constructed by Captains Renard and Krebs of the French army in 1884 and 1885. This balloon (Fig. 2) was of more scientific design than its predecessors, having its largest diameter near the prow, and tapering gradually aft. The volume was comparatively small, only 1,864 cubic metres. As motive power the inventors selected electricity, stored in a battery of thirty-two cells of special construction, and used in an 8·5 horse-power motor, which revolved a 23-foot propeller thirty to forty times a minute. Several successful trials were carried out in August, September, and November 1884, and in August and September of the following year, the highest speed attained being 14 miles an hour. The dirigible overcame winds of considerable strength, and on five of the seven trials returned to its starting-point. It is somewhat strange that the Government did not continue experiments with so efficient an airship, which, in the words of Renard, had "furnished the first proof of the possibility of manœuvring a spindle-shaped balloon in the air ocean by means analogous to those which allow ships to perform evolutions in the ocean of water."

Renard and Krebs' Dirigible.

Successful Trials.

During the years 1898 to 1905 the young Brazilian, Alberto Santos Dumont, designed a series of dirigibles. Henri Deutsch, a wealthy member of the French Aero Club, offered in 1900 a prize of £4,000 to any one who should start from the Aero Club park near Longchamps, sail to and round the Eiffel Tower, and return to the starting-point—a distance of about seven miles—in less than half an hour. After several unsuccessful attempts to capture the prize, M. Santos Dumont succeeded, on October 19, 1901, in covering the stipulated course in a minute less than the limit. The airship used, his No. VI., had a gas bag 33 metres long and 6 metres in diameter, with a volume of 630 cubic metres. An internal air ballonet, fed by a pump, maintained the tautness of the envelope. From the bag was suspended a long truss carrying a basket-work car for the aeronaut, a 16 horse-power Buchet four-cylinder motor, and at the rear end a propeller four metres long, made of silk stretched tightly over a rigid frame. Steering was effected by a vertical rudder operated from a wheel at the front of the car. Santos Dumont's balloons, though not a great advance on that of Renard and Krebs, proved the suitability of

Santos Dumont.

The Deutsch Prize won.

STERN VIEW OF "ZEPPELIN II." (ORIGINALLY NO. III.) LEAVING THE HUGE FLOATING BALLOON SHED AT FRIEDRICHSHAFEN. (*Photo, Topical.*)

Observe the stability planes at the side, the vertical steering rudders between them, and the elevating planes near the keel.

the petrol motor for driving airships, and did a great deal towards stimulating public interest in the possibilities of the dirigible.

Simultaneously with Santos Dumont's experiments at Paris, Count F. von Zeppelin had been busy at Friedrichshafen, on Lake Constance, with the construction of a monster dirigible, which is known as *Zeppelin I.* The envelope was 426 feet long and 37 feet in diameter, its section being that of a twenty-four sided prism. The framework was built of aluminium alloy, and divided into seventeen sections by cross partitions of thin aluminium sheet, which served to insulate the seventeen small balloons used to give buoyancy. The space between the balloons and the outer covering of pegamoid was ventilated by a constant current of air passed through. The volume of the gas chambers totalled 11,300 cubic metres; the weight, including petrol for a ten hours' flight, cooling water for the engines, and a crew of five men, ten tons.

Count Zeppelin's Airships.

Zeppelin I.

In the long keel attached to the under-side of the framework were placed two cars, situated about half-way between the centre and the ends, each carrying a 14·7 Daimler petrol motor. Zeppelin adopted two independent motors, so that, if one should fail, the other would be available for manœuvring the ship and bringing it to earth, if need be. Each motor drove a pair of four-bladed propellers, about 4 feet in diameter, at the very high speed of 1,100 revolutions per minute, through bevel gearing. Reversing gear was included, so that the ship could be moved astern if occasion arose. An installation of electric bells, telegraphs, and speaking tubes assisted the operations of steering.

On July 2, 1900, at 7.30 p.m., the first trial was made. At the signal all ropes were released, and the airship rose and moved against the wind, turning now to the left, now to the right, in answer to the movements of the helm. Unfortunately one of the rudder cables broke, and Zeppelin decided to descend, which he managed to effect without accident. Further trials took place on October 17 and 21. During the first of these the airship remained aloft for eighty minutes; during the second it attained an independent velocity of twenty miles an hour, which quite eclipsed the performance of Renard's *La France*. The tests served to show that, within the limits of its speed, the huge structure could be driven against the wind, and made to circle; also that the design of the framework needed modification to give greater stiffness.

First Trials.

The expense of his experiments had exhausted Zeppelin's finances, and compelled him to appeal to the public for the means with which to continue his researches. But times were bad, and popular interest in aeronautics was as yet unawakened. So four years passed before he had collected sufficient money to construct *Zeppelin II*. This airship had a somewhat larger volume than its predecessor, but was much better engined, two 90 horse-power Mercedes motors taking the place of the two 14·7 horse-power Daimlers. Also, the workmanship and design showed a decided advance. For ascensional purposes, two vertical screws, each giving a lift of 240 lbs., were provided.

Zeppelin II.

The trials, made early in 1906, showed that the new craft was much faster than Zeppelin I., but that it lacked longitudinal stability. On the last trip the steering gear and the motors failed to act, the airship began to drift before the wind, and a descent had to be made into a meadow. During the night, however, a gale arose, drove the airship against a tree, and in a few minutes had reduced it to a complete wreck.

A Disaster.

Count von Zeppelin announced his intention to retire from the field after this disaster, but was persuaded by the Government to persist. Within nine months he had *Zeppelin III*. afloat. This had nearly 4,000 cubic metres more volume than No. II., being of larger diameter and length. Two 110 horse-power motors supplied the driving power. The balloon itself had sixteen sides only, instead of the twenty-four sides used previously, as the reduction of number facilitated construction.

Zeppelin III.

On trial the *Zeppelin III*. proved a great success, carrying eleven passengers sixty-nine miles in 2 hours 17 minutes at an average speed of 35 miles an hour. The Government now came forward with the offer to purchase an airship for £100,000 if it could make a continuous flight of twenty-four hours, and land safely. Accordingly, Zeppelin busied himself on the construction of No. IV., wherewith to fulfil the conditions laid down. This ship was ready by the beginning of June 1908. On July 1 she left Friedrichshafen, and travelled westwards along the north shore of Lake Constance towards Schaffhausen. Just before reaching this town she turned southwards and made for town and lake of Lucerne, round which she passed without difficulty. Thence the course was set northwards to Zürich, and, after that city had been passed, eastwards over Sulgen and Romanshorn to the east end of Lake Constance, and so back to the great floating shed at Friedrichshafen. A distance of 236 miles had been covered in twelve hours—an average of 18½ miles an hour—without mishap of any kind. The world was electrified by a performance which threw completely into the shade all previous achievements of dirigibles.

Zeppelin IV.

A Trip over Switzerland.

On Tuesday, August 4, 1908, Zeppelin set out on his first attempt to win the Govern-

"ZEPPELIN IV." ROUNDING STRASSBURG CATHEDRAL SPIRE DURING THE VOYAGE WHICH ENDED IN HER TOTAL DESTRUCTION AT ECHTERDINGEN.

(*Photo, Scherl.*)

ment subsidy with a twenty-four hours' flight. Following the course of the Rhine, the airship passed Basle, Mülhausen, Strassburg, Mannheim, and reached Mainz, after a voyage lasting 16 hours 40 minutes.

A Fine Voyage ends in Disaster.

After a descent to make some trifling repairs, the homeward journey began. The great envelope had, however, developed leaks, which, coupled with irregular working of the motors, compelled the count to descend at Echterdingen, near Stuttgart. While the balloons were being inflated a squall struck the ship, and bumped it violently against the ground. Some petrol ignited, and in a moment the conflagration had reached the highly inflammable hydrogen in the balloons. A few minutes sufficed to destroy the work of months.

This heavy misfortune, coming on the top of a great triumph, roused the patriotism of Germany in a manner that may serve as an object lesson to other nations. Within a few weeks £300,000 were subscribed to enable the aged Count to build yet more Zeppelins for the use of his countrymen.

Zeppelin III. was taken in hand, increased as to its length and carrying power by the addition of one more balloon, renamed *Zeppelin II.*, and, after some very successful tests, taken to Metz to form a unit in the aerial fleet that now has its headquarters on the frontier.

Zeppelin II. (new style) is the same size as No. IV., and has to its credit the longest of all airship voyages. On May 29, at 9.42 p.m., it left Friedrichshafen, and took an almost direct line for Berlin, 360 miles distant. The huge dirigible passed over Ulm, Nuremberg, Bayreuth, Plauen, and Leipzig. At the last-named place Zeppelin threw over a telegram addressed to the emperor, expressing his hopes that he might be able to reach Berlin, only 125 miles away, that day. The news spread through Berlin like wildfire; the whole population turned out to welcome the Count. But a northerly breeze arose and developed steadily into so high a wind that Zeppelin, on reaching Bitterfeld, decided to turn the airship about and run southwards. Late in the evening the inhabitants of Halle and Weimar saw *Zeppelin II.* pass overhead. By 4.45 next morning she reached Würzburg. Five hours later she was circling the spire of Stuttgart Cathedral. The ship then proceeded to Kirchheim, where the petrol supply began to show signs of exhaustion. At Göppingen a descent was decided upon. During an attempt to land, the airship was caught by a squall and driven violently against a tree, which smashed in her bows and held her prisoner, her stern floating well above the ground. Thus ended a 38-hour journey, during which well over 600 miles—some calculations make the figures 950, but this is probably excessive—had been covered. Even the records of *Zeppelin IV.* had "gone by the board." Though this remarkable achievement also ended in disaster, after temporary repair the airship was able to make its way, with but one rudder running, to Friedrichshafen, where, in the course of a few weeks, it was put into good running order again.

A Record Journey of over 600 miles.

Collision with a Tree.

The latest of the Zeppelins, No. III., has three motors of 150 horse-power each, but has not, up to the time of writing, performed any sensational feat. In general features the Zeppelin type has not undergone much alteration. Power, volume, and lifting capacity have been increased, the steering apparatus has been improved, and great accommodation for the crew provided. The rigid, subdivided gas-holder is retained, despite the criticisms of the "non-rigid" school. Count von Zeppelin has boundless faith in his own invention. So far from being discouraged by the mishaps which must be expected to occur while the lessons of aeronautics are being learnt, he has propounded a scheme for running regular airship services, as a commercial venture,

THE FRENCH DIRIGIBLE "ZODIAC III." *(Photo, Topical.)*

The pipe and pump for keeping the internal air-ballonet inflated are noticeable features. Elevated planes mounted on front of the car. Rudder attached to under-side of the balloon. Non-rigid type.

between Berlin and Copenhagen, Stettin, Bremen, Cologne, Stuttgart, and other important centres, besides pleasure trips down the Rhine into Switzerland.

FRENCH DIRIGIBLES.

The *Lebaudy* Airship.

The *Lebaudy* airship, built by Julliot and Surcouf in 1902, is of the semi-rigid type, with a keel-shaped floor made of steel tubes. Length, 56·5 metres; greatest diameter, 9·8 metres; volume, 2,784 metres. The car is slung from the floor by steel rods. A 40 horse-power motor operates two screws, one on either side of the car, each 9 feet in diameter. With the engine running at 1,050 revolutions a minute, the thrust of the propellers totals 350 lbs. In 1902, 1903, and 1905 the *Lebaudy* made many successful trips, ranging up to nearly 100 kilometres. The airship behaved so satisfactorily—especially after certain alterations and improvements had been carried out—that it was finally adopted for the French army, and is still in commission.

The *Patrie* and *République*.

Two other dirigibles, *La Patrie* and *La République*, were subsequently constructed on *Lebaudy* lines. The *Patrie* delighted the Parisians in 1907 by a number of evolutions over the capital, and at the end of November made a memorable voyage of 230 kilometres from Paris to Verdun, near the German frontier. Only 140 out of the 190 litres of petrol, and but a small part of the ballast, were used, so that the journey could have been extended for many miles. During part of the trip the elevation was about 3,000 feet. (A few days before the start the *Patrie* had proved her ability to rise 1,300 metres, or 4,300 feet, the record at that time for dirigibles.) Shortly after arriving at Verdun, the *Patrie* was overtaken by a gale while at anchor. A large body of soldiers detached to hold her down kept her captive for some hours. Then she broke away and was swept into the clouds,

travelling north-westwards at a high speed. Probably she passed over England and Ireland, and fell into the Atlantic Ocean.

Details of the *Patrie*.

Some details of this airship will be of interest. Length, 197 feet; maximum diameter, 33¾ feet; volume, 111,250 cubic feet; stern provided with an *empennage* (or feathering, like that of an arrow) of two vertical and two horizontal planes, to maintain stability; ballonet, having capacity of one-fifth of the total volume, divided into three compartments by perforated partitions to prevent surging of the air to and fro; boat-shaped car, 16 by 5 by 2½ feet, attached by triangulated steel cables to the rigid frame under the gas-bag, the two last being held together by a net; frame easily released from net, and taken to pieces for transport; car furnished with pyramidal sub-structure to take the shock of landing. A motor of 70 horse-power drove two steel propellers, 8½ feet in diameter, and mounted on each side of the car, at 1,000 or more revolutions per minute. The frame carried vertical and horizontal stabilizing planes and a vertical rudder, and a movable horizontal plane was fixed above the car to cause ascent and descent without loss of gas or ballast.

The *République*.

The *République* was very similar to the *Patrie*. It had 2,000 cubic feet more volume, but a somewhat less powerful motor. It made some very good flights, and took part in the French army manœuvres of 1909. While returning from these to Chalais Meudon, she was destroyed by a propeller blade coming adrift and splitting the balloon. The airship fell 700 feet, and her crew of four men were killed instantaneously.

La Ville de Paris belongs to the non-rigid class. Built in 1906 by Surcouf. Length, 200 feet; maximum diameter, 34½ feet; volume, 3,200 cubic metres. The ballonet

THE "CLEMENT-BAYARD I." ENTERING ITS SHED. (*Photo, Topical.*)

Observe the great stabilizing ballonets at the stern.

FRENCH NON-RIGID AIRSHIP "VILLE DE PARIS." LARGE TRACTOR SCREW IN FRONT.
Length, 62 metres; greatest diameter, 10·5 metres; volume, 3,200 cubic metres; horse-power of motor, 70.
(*Photo, Topical.*)

The *Ville de Paris.*

is divided fore and aft into three compartments by curtains of permeable cloth, not fixed at the bottom, so that when the ballonet is distended air can pass easily from one compartment to another. The car is very long and heavy, and is attached to the gas-bag by a number of ropes running to canvas bands sewn to the side of the bag. This "long" suspension gives a good distribution of weight. A single propeller of large diameter is mounted at the front of the car, and driven by a 75 horse-power motor at 980 revolutions per minute. The distinguishing feature of the *Ville de Paris* is the eight small cylinders, arranged in groups of two, which take the place of the vertical and horizontal stability planes of the *Patrie*. Their weight is exactly equal to the buoyancy of the gas which they contain, so that they have no ascensional effect. They are said to serve their purpose very well, but, in spite of their conical forward ends, cause a drag which militates against high speed.

Clément-Bayard I.

The *Clément-Bayard I.*, designed by M. A. Clément, the founder of the famous French motor-car firm, was completed in 1908. Length, 56·25 metres; maximum diameter, 10·58 metres; volume, 3,500 cubic metres. The bag has at the tail four large pear-shaped gas ballonets, which communicate with the main bag through holes pierced in the envelope. The air ballonet is unusually large, and has a volume of 1,100 cubic metres. The car is built of steel tubes, and covered with cloth and aluminium sheeting. The vertical rudder has two parallel planes of steel; the horizontal rudder three superposed planes, with a total surface of 16 square metres, and is set slightly forward of the centre of gravity. Both rudders are balanced and operated

through steel cables by irreversible tillers. To diminish vibration, and to enable the instruments in the car to be read more easily, the engine is mounted on a system of springs.

The *Ville de Bordeaux* and *Colonel Renard* have the same general features as the *Clément-Bayard I.* The *Clément-Bayard II.*, built for trial in England, is the largest of all non-rigid airships. It measures 300 feet from stem to stern, and has a volume of 6,300 cubic metres. The bag has a blunt nose and a long conical body and tail. In place of the stabilizing ballonets of *Clément-Bayard I.*, she carries a vertical plane under the tail. Close to this is the vertical rudder for lateral steering. To distribute the weight of the engines, passengers, etc., a car 140 feet long is slung from the gas chamber. About one-third of it is available for the engines and living freight.

Clément-Bayard II.

The *Clément-Bayard II.* is engined with two 220 horse-power motors set amidships to drive a couple of two-bladed wooden propellers, 20 feet in diameter, mounted on either side of the car, and revolving in opposite directions. The lifting power of the airship is sufficient to raise twenty-five passengers and enough petrol for a six or seven hundred-mile journey. It is expected that a speed of at least 35 miles an hour will be attained. This airship will be the great rival of the Zeppelins; her carrying power, speed, and radius of action should prove as great, and she may show herself superior as regards alighting and manœuvring.

In Germany it is recognized that, though the Zeppelin type may have decided advantages for long trips, smaller dirigibles with collapsible gas chambers are more suitable for military purposes. The first non-rigid

GERMAN NON-RIGID "PARSEVAL II." FLYING OVER THE TEGELER GROUNDS. (*Photo, Topical.*)

Note the hemispherical prow and conical stern. This balloon has two internal ballonets, and a pump for transferring air from one to the other to regulate the longitudinal trim. Length, 58 metres; greatest diameter, 9·5 metres; volume, 3,800 metres; horse-power of motor, 114.

TAKING OBSERVATIONS FROM A MILITARY DIRIGIBLE BALLOON.

German dirigible, *Parseval I.*, appeared in 1906. It had a hemispherical prow and a conical stern. Two air ballonets are used, one at each end, to control the longitudinal trim of the gas chamber. For ascending, the rear ballonet is filled and the front ballonet emptied, throwing the centre of gravity of the gas forward, and causing the prow to rise and give the under surface of the bag somewhat of an aeroplane effect. For descending the process is reversed.

The Parseval.

"GROSS II.," THE GERMAN SEMI-RIGID MILITARY AIRSHIP, IN FLIGHT. (*Photo, Topical.*)

In general outline it closely resembles the *Parseval*, but is distinguished by the girder keel from which the car is suspended. This ship was used during the German army manœuvres of September.

Two other interesting points are the car suspension and the propeller. The car has two pulley wheels on each side at the floor level, round which pass steel cables to the ropes distributing the weight over the whole length of the gas-bag. This arrangement allows the car to adjust its position in accordance with variations of the screw thrust and air pressure. The propeller has four blades of cloth weighted with lead. When at rest the blades hang limp, but are stiffened by centrifugal force when revolving. Weight is reduced considerably by this system of blading. Larger and more efficient Parsevals were built in 1908 and the present year. *Parseval II.* is 58 metres long, has a volume of 3,800 cubic metres, and carries a 114 horse-power engine.

The Gross Airships.

The *Gross I.*, launched in 1907, is a semi-rigid dirigible, with spherical prow and stern. The latest Gross has a volume of 5,000 cubic metres, and includes two air ballonets. The two 3-bladed propellers revolve in the same direction. At the rear, horizontal planes are used for stability. We may note that the inventor, Von Gross, has abandoned the hemispherical in favour of the conical stern.

In America the Baldwin airship has achieved considerable success, and has been adopted

by the United States army. It has a pointed stem and stern; a long car attached close to the gas-holder; elevating planes at the fore end, and a vertical rudder at the rear of the car; and a single tractor screw. On its official trials this airship made an independent speed of nearly 20 miles an hour.

The Baldwin Airship.

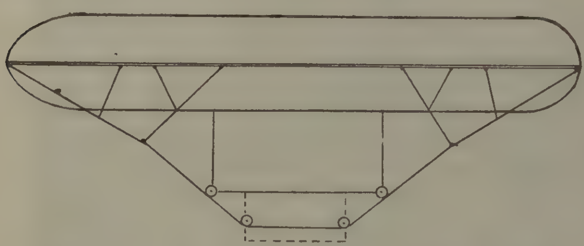


DIAGRAM TO SHOW THE METHOD USED FOR SUSPENDING THE CAR OF "PARSEVAL II."
The cords pass round rollers which allow the car to retain its horizontal position when the balloon tilts.

The list of the world's airships cannot be made complete, as at the time of writing many dirigibles are in course of construction or on trial for all the great Powers. In England a huge rigid airship is being built at Barrow. The Germans have a dozen or more in hand. Russia, Japan, Italy, Belgium, Austria, Spain, and the United States are all busy.

The Continental Tyre Company's fabric is most commonly employed for the gas chambers of dirigibles. It is built up of four layers. Beginning on the outside, we have—(1) Layer of cotton cloth impregnated with yellow chromate of lead to keep out the actinic (blue to ultra-violet) rays of the sun, which do damage to rubber; (2) layer of vulcanized rubber sheeting to retain the gas; (3) layer of cotton cloth to reinforce that on the outside; (4) thin layer of vulcanized rubber to protect the cotton against the chemical action of the hydrogen gas. In the Gross airships this layer is dispensed with.

Material used for Balloons.

The four-layer fabric weighs slightly under ten ounces per square yard. A strip one foot wide will bear a strain up to 950 lbs. before tearing. The two layers of cotton cloth are laid diagonally to one another, so that the warp of the one may resist ripping in the weft of the other, and localize injuries to the fabric.

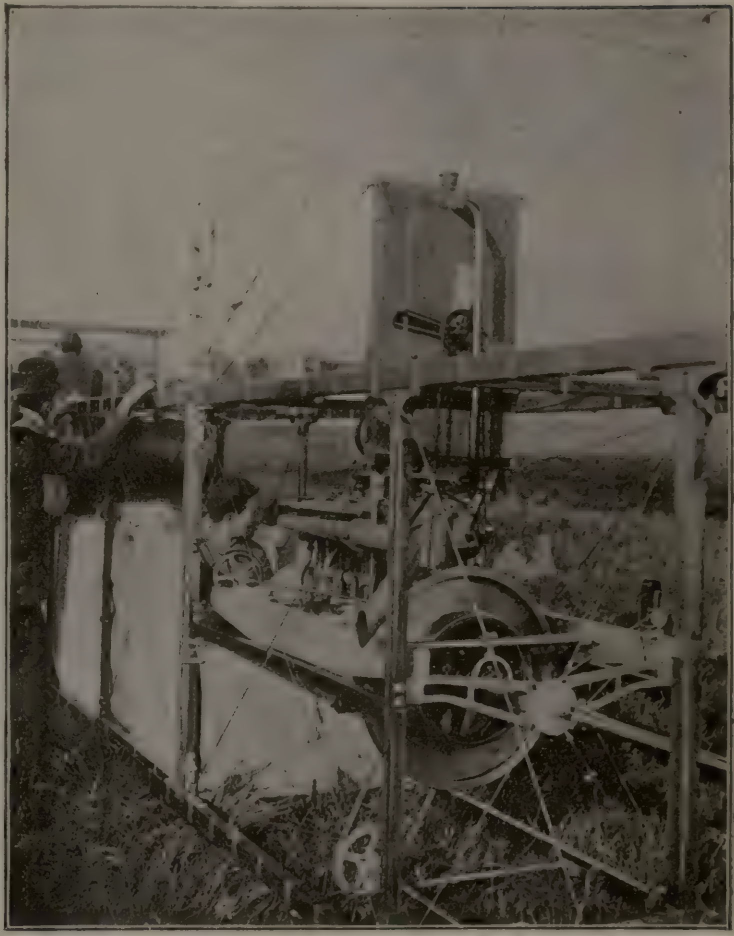
Nulli Secundus II., the very moderately successful British army airship, had a bag built up of many layers of gold-beater's skin, a very tough and impermeable but also very expensive material.

There is no denying the fact that, whereas the development of and interest in the flying machine have been due largely to what one may call the sporting instinct, the dirigible balloon is considered primarily to be an instrument of war. The value of being able to see and give information of what the enemy is doing, without incurring great risks, is of such value to a military commander that in the next great war the dirigible balloon will certainly be very fully tested. In rough weather it will be of no more use than the ordinary spherical balloon; but that fact will not prevent its being kept ready for ascent under favourable conditions. As for the danger from gun fire, this would be minimized by rising to great heights; and one cannot imagine a dirigible being employed that was not capable of ascending 5,000 to 6,000 feet above the earth's surface, if it had to be sent directly over the enemy's position. Even a much less height would allow its passengers to make observations, while keeping out of range. In the grim business of war bold spirits would not be wanting to take heavy risks on the chance of winning through—to play the counterpart of the naval scout. For several years to come, however, the dirigible will be used for observation only, not for dropping explosives or incendiary substances. Possibly a dirigible may have to attack the air craft of the opposing forces, and to that end might be furnished with small guns; but

The Dirigible in Warfare.

it would take no part as combatant in a general engagement. As for aerial invasions — great numbers of men wafted through the air on to the enemy's country —they will not happen for many years to come.

The military value of airships was tested at this year's manœuvres of the French and German armies, *La République* and *Gross II.* being selected for the purpose by the respective Governments. The *Gross II.* got within rifle range, and was ruled out of action, but subsequently was "restored" to her side and did good work. The *République* managed to get over the "enemy" during a thick mist, and when the latter cleared away, and while the troops below were gaping in astonishment, feeling like partridges under a hawk, those on board the airship took full and accurate notes of the disposition of the attacking force and sailed away.



ENGINES OF "ZODIAC III." (*Photo, Topical.*)

The flying machine has also to be taken into consideration. When it is able to rise to heights comparable with those of a balloon, and maintain its elevation for an hour or two at a stretch, it will be practically safe. Its small size and speed will render the chances of its being hit, even by guns that could reach it, quite negligible. We may fitly close this side of the subject with the weighty words of Sir Hiram Maxim : "The value of a successful flying machine, when considered from a purely military standpoint, cannot be over-estimated. The flying machine [we may add the navigable balloon] has come to stay, and whether we like it or not, it is a problem that must be taken into serious consideration. If we are laggards, we shall unquestionably be left behind, with a strong probability that before many years have passed over our heads we shall have to change the colouring of our school maps."

RECORDS OF DIRIGIBLE BALLOONS.

Date.	Name.	Place.	Type.	Duration of Flight.	Distance.	Remarks
1852 Sept. 24.	Giffard's.	Paris.	Non-rigid.	......	......	Velocity, 5 miles per hour. First power - driven dirigible.
1884. Aug. 9.	La France. (Renard & Krebs.)	Meudon, France.	,,	......	......	First practical dirigible to return to starting-point. Velocity, 10 miles per hour.
1885. Sept. 23.	,,	,,	,,	......	......	Velocity, 14 miles per hour.
1898. July 2.	Zeppelin I.	Friedrichshafen, Germany.	Rigid.	1 hr. 20 min.	......	Velocity, 16 miles per hour.
1902. Oct. 19.	Santos Dumont VI.	Paris.	Non-rigid.	30 min. 40 sec.	7 miles.	Circled Eiffel Tower; won Deutsch Prize.
1903. May 8.	Lebaudy.	Moisson, France.	Semi-rigid.	1 hr. 36 min.	23 miles.	Velocity, about 20 miles per hour.
May 15.	,,	,,	,,	1 hr. 41 min.	38½ miles.	,,
June 24.	,,	,,	,,	2 hr. 46 min.	60 miles.	,,
1905. July 3.	,,	Moisson—Meaux.	,,	2 hr. 37 min.	89 miles.	First stage on journey to eastern frontier.
July 4.	,,	Meaux—Sept Sorts.	,,	47 min.	11 miles.	Second stage on journey to eastern frontier.
July 6.	,,	Sept Sorts—Châlons.	,,	3 hr. 25 min.	61 miles.	Third stage on journey to eastern frontier. Balloon collided with a tree, and was destroyed.
Nov. 10.	,,	Toul, France.	,,	......	......	Reached height of 4,500 ft.
1906. Oct. 10.	Zeppelin III.	Friedrichshafen.	Rigid.	2 hr. 17 min.	69 miles.	
1907. Sept. 30.	,,	,,	,,	8 hr.	211 miles.	Velocity, 35 miles per hour.
Oct. 5.	Nulli Secundus.	Aldershot—London.	Non-rigid.	3 hr. 25 min.	50 miles.	Velocity, 12 miles per hour.
Oct. 28.	Parseval I.	Berlin.	,,	6 hr. 25 min.	......	......
Oct. 28	Gross I.	,,	Semi-rigid.	8 hr. 10 min.	......	......
Nov. 23	La Patrie.	Paris—Verdun.	,,	6 hr. 45 min.	146 miles.	Velocity, 26 miles per hour.
1908. Jan. 15.	Ville de Paris.	,,	Non-rigid.	7 hr. 6 min.	146 miles.	......
July 1.	Zeppelin IV.	Friedrichshafen.	Rigid.	12 hr.	236 miles.	Circular journey over Switzerland.
Aug. 4.	,,	Friedrichshafen—Oppenheim.	,,	11 hr. (first stage only).	258 miles.	Destroyed at Echterdingen on way back to base.
Sept. 11.	Gross II.	Tegel—Magdeburg—Tegel.	Semi-rigid.	13 hr. 15 min.	176 miles.	Reached height of 4,000 ft.
Sept. 15.	Parseval II.	,,	Non-rigid.	11 hr. 32 min.	157 miles.	......
Oct. 6.	Lebaudy.	Moisson.	Semi-rigid	......	......	Reached height of over 5,000 ft.
Oct. 22.	Parseval II.	Tegel.	Non-rigid.	......	......	Maintained height of 5,000 ft. for over an hour.
1909. May 29–31.	Zeppelin II. (New).	Friedrichshafen—Bitterfeld—Göppingen.	Rigid.	37 hr. 40 min.	603 miles.	Record duration and distance. On landing, the dirigible was damaged, but continued its journey to Friedrichshafen.
Aug. 4.	Gross II.	Berlin—Apolda—Berlin.	Semi-rigid.	16 hr.	290 miles.	
Aug. 23.	Clément-Bayard.	Sartrouville, France.	Non-rigid.	......	......	Remained for two hours at height of over 4,000 ft.

[*We have pleasure in acknowledging the help given in the preparation of these articles on aeronautics by the Aeronautical Society of Great Britain; Mr. T. W. Clarke; and Mr. H. Ledeboer, Editor of "Aeronautics."*]

HARBOUR CONSTRUCTION—LOWERING A HUGE CONCRETE BLOCK.

IN a previous article (Vol. I., p. 370 foll.) has been described the extremely arduous work of the lighthouse engineer and the nature of the terrific destructive forces with which he has to contend. Another branch of marine engineering, that of harbour construction, is beset with the same difficulties, though possibly in not so aggravated a form, as harbour works are not so isolated as the rocks on which lighthouses have to be raised.

Breakwaters.

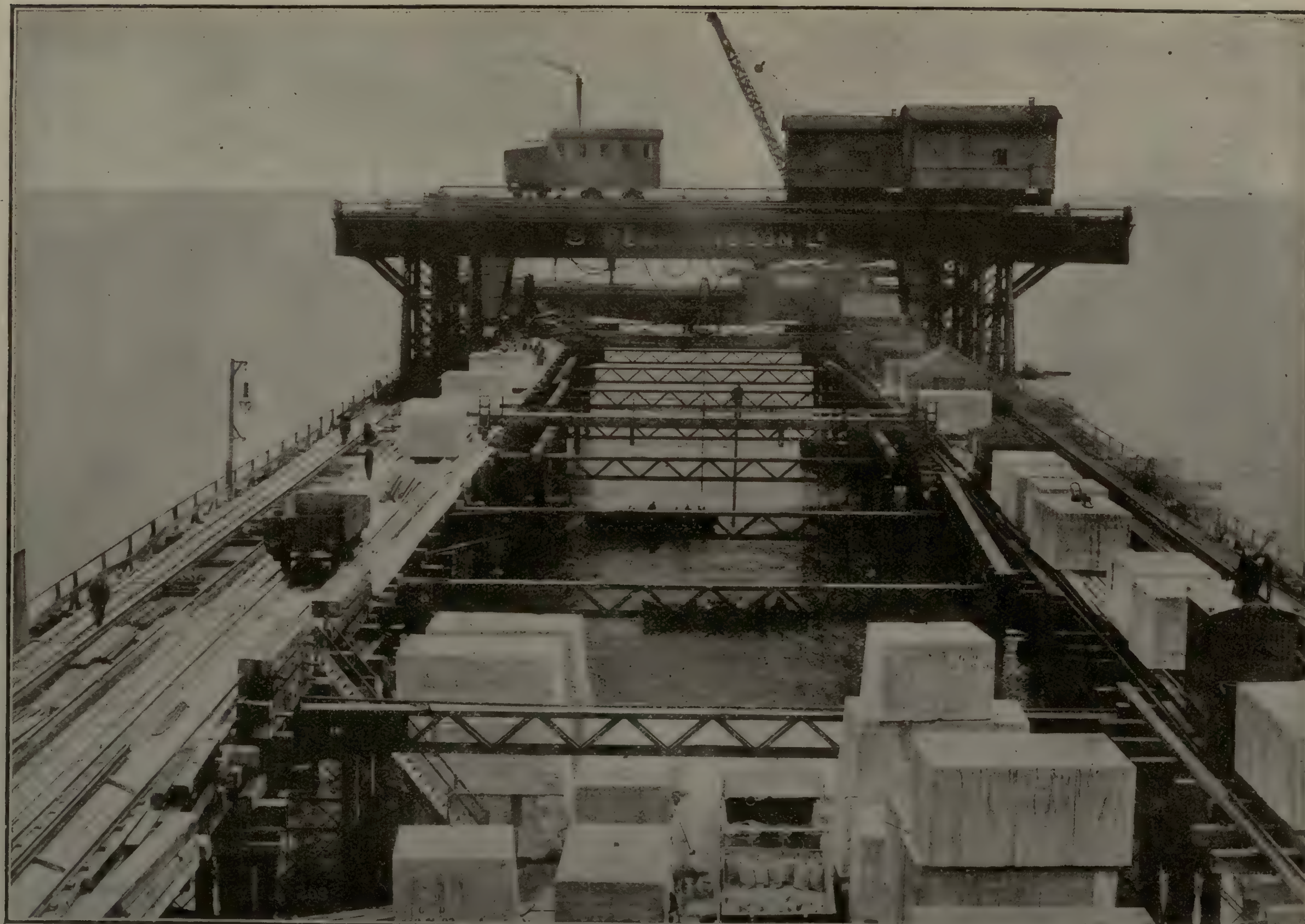
We are concerned here primarily with works carried out to oppose the violence of the waves, and to render safe for shipping areas of water which, but for some such protection, would be utterly unsuitable for anchorage in bad weather. The breakwater is a mere barrier, either reducing the size of a wave or checking its progress altogether. Its shape and character depend partly on the conditions of the site, partly on the work for which it is designed. It may be either an artificial bank of rubble with long slopes paved on the top; or a rubble mound brought up to within a few feet of low-water level at spring tides, and capped with a built pier; or a more or less vertical wall based upon the sea bottom. The breakwaters of Plymouth, Portland, and Dover Harbours respectively are good examples of the three types. We may add that different forms of construction are found in some cases in one breakwater at different depths of water. Thus, what begins at the shore end as a wall built on the bottom may be given a footing of rubble, the height of which increases with the declination of the ground, as it progresses seawards.

Waves: their Motion and Force.

Before going further into our subject, a few words on the nature of waves will be of value. There are two main orders of waves: (1) waves of *translation*, in which the bulk of water moves bodily in the direction of the wave, as when a wave breaks on the beach; (2) waves of *oscillation*, in which the particles move vertically as well as horizontally, the motion being that of a mass rolling along a surface. Towards the top of the wave the particles move in the direction of the wave; in the trough, in the opposite direction. The motion is greater at the crest and in the trough; least at half height of the wave. The destructive power of a "roller" is proportionate to its height. A wave thirty feet high may produce a pressure of one ton on every square foot of a surface opposing it squarely. Even much higher pressures have been recorded—nearly three tons per square foot at Skerryvore Lighthouse, and three and a half tons at Dunbar.

On entering shallow water a roller becomes a wave of translation, and hurls itself horizontally against any obstacle.

To rob a wave of its onward movement, two methods, used singly or in combination, are employed. The first is to offer a long incline to the wave, up which it must rush,



DIVERS AT WORK, DOVER HARBOUR. *(By permission of Messrs. S. Pearson and Son, Ltd.)*

This view gives a good idea of the enormous size of the Goliath cranes used.

A HUGE TITAN CRANE LIFTING A 35-TON LOAD. *(Photo, Messrs. Ransomes and Rapier.)*

Working radius, 67 feet. Weight, 320 tons.

and so expend its energy in climbing. When its force is exhausted, the wave falls back on the slope and rushes down again, its momentum assisting to stem the violence of the succeeding wave. The second method is to employ a more or less vertical wall, which suddenly converts horizontal into vertical motion. The wave, on reaching the face, climbs up it, and then sinks, causing a seaward reflection of the undulating movement.

Methods of Wave-stopping.

The effects of a wave are comparatively slight below the trough, and decrease rapidly with the depth. Hence below low-water level rubble mounds can be given a steep pitch, and be made of smaller stones than would be needed at and above water level. This is the general rule. But there are instances to prove that wave action extends, under certain conditions, to a much greater depth than was once supposed. Sir William Matthews, the celebrated harbour engineer, records that at Peterhead breakwater, during a storm in 1898, blocks weighing upwards of 41 tons were displaced at a level of nearly 37 feet below low water of spring tides, and that a section of the breakwater, weighing 3,300 tons, was slewed bodily two inches without breaking the joints. It is estimated that to effect this a pressure of two tons per square foot below as well as above normal water level must have been required. The same authority also relates that the north pier at the entrance to

Terrific Force of Waves.

the Tyne was founded on a rubble base, which, at the outward end of the pier, had its crest 27 feet below water; the top of the mound was protected by an apron of 41-ton concrete blocks; yet winter storms drew out blocks until it became necessary to rebuild 1,500 yards of the pier.

A TITAN SETTING A 40-TON APRON BLOCK AT SOUTH SHIELDS BREAKWATER.
Crane built by Messrs. Stothert and Pitt, Bath.

A thorough investigation of the physical conditions of the site must precede the preparation of a design for a harbour. To quote Sir William Matthews: "This examination should have special reference to exposure, the set and velocities of the currents, the possibility of shoaling consequent upon the proximity of accumulations of sand or shingle, the nature and depth of the shelter required and its extent, the character of the strata to be dealt with, of the materials and local labour available, and many other points, each of which demands careful and minute investigation."

Preliminary Investigation.

For localities where tides are small, as at Portland, Plymouth Sound, and Cape Town, the rubble mound form of breakwater is well suited. On the score of rapidity of construction and minimum cost, the concrete wall, formed either of mass concrete moulded *in situ*, or of blocks manufactured in special yards and carried to the spot, is now adopted widely. It is not overstating the case to say that the discovery of Portland cement has revolutionized the art of harbour construction, by furnishing the engineer with a ready means of overcoming the violence of the ocean by the

Portland Cement.

sheer weight of the bodies placed in the path of the waves. As Mr. Alan Stevenson pointed out sixty years ago, mass rather than cohesion is the quality on which the harbour engineer must depend for the stability of a wall. A single concrete block weighing 40 tons is much more reliable than four blocks of ten tons each bonded and tied together with the utmost human art. A joint means potential weakness.

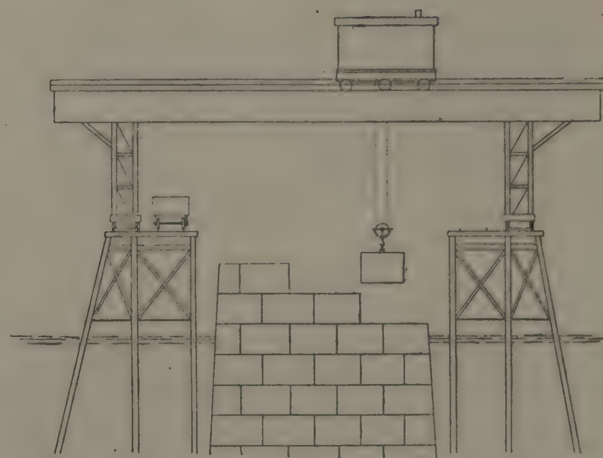


DIAGRAM TO ILLUSTRATE THE GANTRY SYSTEM OF LAYING BLOCKS.

The building of efficient concrete block breakwaters has been greatly assisted by recent improvements in cranes of the "Titan" and "Goliath" types. The first of these has a large carriage supported on a number of wheels running on a wide-gauge railway laid along the completed portion of the breakwater. The wheels are furnished with springs to allow for inequalities in the track. Across the carriage run two large girders braced together horizontally, and pivoted on a pin which is set at the centre of a circle of rollers interposing between a path on the summit of the carriage, and a similar path attached to the underside of the girders.

Giant Cranes.

On the short arm of the girders are stationed a movable counterweight and the steam-engine which swings the arm round, operates the hoisting tackle, and, on being connected up through gearing with the track wheels, moves the crane bodily backwards or forwards.

The largest Titans have an "overhang," measured from the centre of the pin to the extreme limit of which the hoisting carriage can be moved out along the longer arm, of about 100 feet, and so are able to pick up or deposit a block weighing anything up to 50 tons within a circle 200 feet in diameter. A liberal overhang is of great importance when large blocks are handled, as the blocks are necessarily laid in courses, the outer ends of which form a series of steps. The deeper the water the greater is the number of steps, and the further is the bottom step from the last completed top course. Hence it follows that a crane with a very big reach can lay blocks in a depth of water which would with a crane of smaller reach necessitate the use of smaller blocks.

"Overhang."

The great advantages of this type of crane are that in stormy weather it can be withdrawn out of reach of the waves, assuming that the breakwater has connection with the shore; and that, as it builds its own path, no trestle work or other special structures liable to damage are required. On the other hand the "Goliath" or gantry crane, running on tracks supported by rows of piles driven ahead of the block laying, and spanning the area to be covered by blocks, is able to assist in preliminary operations, such as levelling the surface on to which the blocks will be lowered, as we shall notice later on when dealing with the Dover Harbour Works. Also a long "working end," allowing the lowest course to be laid over a considerable area before the upper courses are superimposed, minimizes the cracks and settlements which sometimes occur when the short working end associated with the Titan is used.

Titan *v.* Goliath.

Coming now to a brief review of some of the most notable artificial harbours, the first place

is taken chronologically and otherwise by the immense *digue* protecting Cherbourg Harbour.

The Cherbourg *Digue*.

It was begun in the time of Louis the Fourteenth, and after being severely damaged and repaired several times, was finally reconstructed in 1832. Its total length is 4,120 yards, or about 2⅓ miles, making it the longest single breakwater in the world. It consists of two arms, 2,441 and 1,679 yards long, forming with each other an angle of about 170 degrees. At each extremity, and at the point of junction of the arms, provision was made for a large circular fort. This remarkable mole shelters an area of nearly 2,000 acres, being assisted by a 500-yard breakwater running out from the shore towards its eastern end. As it stands to-day, the *digue* consists of a rubble bank faced with a thick blanket of hydraulic concrete, and topped by a wall of granite masonry. The wall is protected on the sea slope by blocks deposited "random."

The great breakwater in the entrance to Plymouth Sound owes its existence to the genius of the famous engineer, John Rennie. In 1811 an Order in Council was issued allowing Rennie to commence the gigantic task of forming, with stones deposited from barges, a dike a mile long, 55 yards wide at the base and 10 yards wide at the crest.

Plymouth Breakwater.

The breakwater was to be quite isolated, and have a straight central part 1000 yards in length, with terminal wings, each 350 yards long, inclined at a very obtuse angle to the main portion.

Rennie's method was to dump the stones in mass along the line of the breakwater, and to allow the waves, which, he declared, were the best possible workmen obtainable, to move the

A BLOCK-MAKING YARD, DOVER HARBOUR WORKS.

Some of the concrete blocks weigh over forty tons each.

blocks until they lay on the natural slope assumed by loose stones subjected to the action of heavy waves. This slope he had already decided, after careful observation, to be one of about 1 in 5.

The first stone, a large block of marble, went into the water on August 12, 1811. During the next two years barges brought their loads from quarries on shore, and dumped them through trap-doors in their bottoms along the line indicated by buoys. For more than a year the work had no visible effect in calming the waters of the Sound, and people who did not understand the nature of the task began to grumble about the great expense and waste of money. In March 1813, however, the stones began to show above water, and popular opinion ran strongly in Rennie's favour. At the end of August 1815 nearly 650,000 tons of stone had been deposited, bringing 1,100 yards of the breakwater above low-spring tides. In this year the captive Napoleon, as he passed into Plymouth Sound, expressed his admiration at the boldness and great scale of the undertaking. Throughout 1816 stone was deposited at the rate of 1,030 tons per day—a record which could hardly be beaten at the present time, in spite of the great improvements in methods of handling material; and by December 300 yards of the mole stood out 20 feet above low water of spring tides. Rennie had been severely criticised by his employers for using so gradual a slope as 1 in 5, and thereby greatly increasing the

INSIDE ONE OF THE DIVING-BELLS USED FOR LEVELLING THE SEA BOTTOM FOR THE CONCRETE BLOCKS, DOVER HARBOUR WORKS.

WEST END OF THE ISLAND BREAKWATER, DOVER HARBOUR, SHOWING GRANITE MASONRY FACING OF THE BLOCKS.

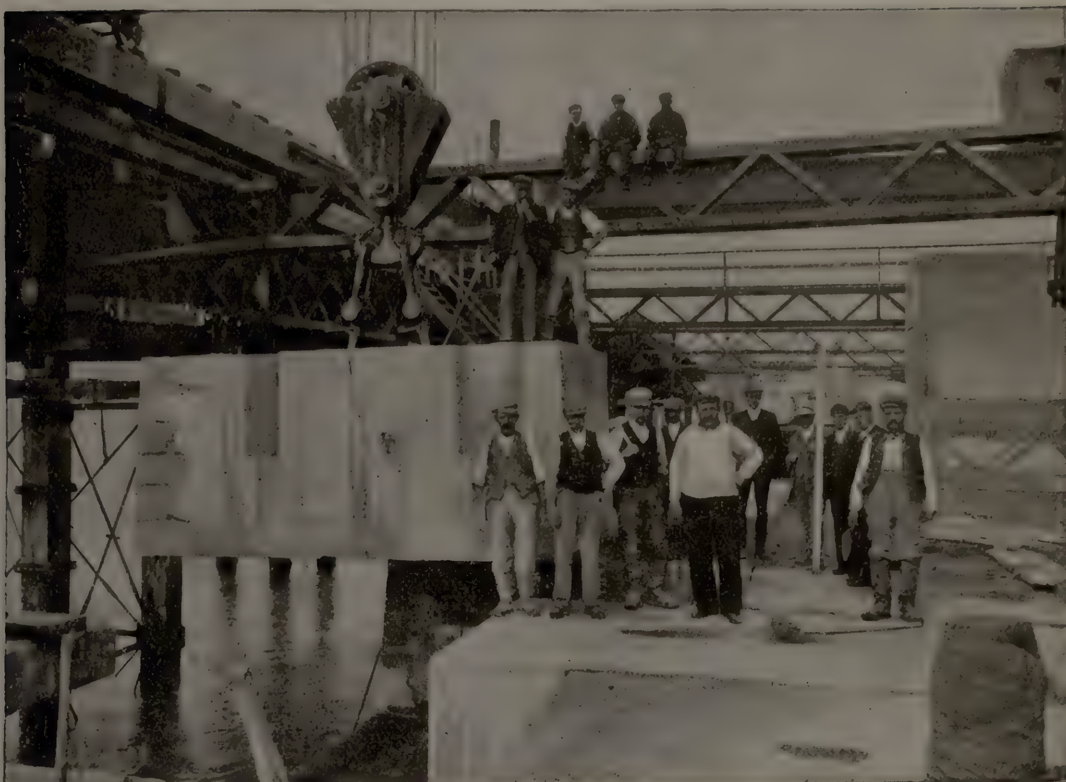
total quantity of stone required. In deference to the critics, but against his own convictions, he altered the seaward slope to 1 in 3. In January of 1817 severe gales raged for several days. As soon as the weather permitted the ridge to be examined, it was found that a considerable part of the slope had been converted from 1 in 3 to 1 in 5 by the waves, which had flung great blocks of stone over the crest on to the leeward face. In spite of this object lesson no alteration in the plans was made, and the work went on as before.

Rennie justified by Storms.

John Rennie died in 1821, long before his greatest enterprise in marine engineering had been completed. An even more violent storm than that just referred to came in November 1824, and again proved the engineer to be right, by reducing the slope for a distance of 800 yards. The authorities therefore decided to follow Rennie's original advice. The breakwater was completed—but not until 1848—on the 1 in 5 slope, and, to prevent the displacement of rubble at and above low-water level, the faces and top were protected by large blocks of stone carefully shaped and cemented and dovetailed together. During construction the width at top was increased to 11 yards, and at bottom to 133 yards.

Altogether, the breakwater consumed 3,670,444 tons of stone and 22,147 cubic yards of masonry, the placing of which cost the nation a million and a half sterling. Yet the money was well spent, as the Sound is now well sheltered from the gales, even such waves as pass over the breakwater being so reduced in size that they interfere but little with the shipping inside.

The Holyhead breakwater exceeds consider-



LOWERING A 40-TON BLOCK, DOVER HARBOUR.

ably in mass that just described. It is 7,860 feet long, and has a greatest width at bottom of 460 feet, and a maximum height of about 65 feet, including the wall built on the rubble mound. The engineer, the late Mr. J. M. Rendel, was enabled, owing to the land connection, to use trucks running on stagings supported by piles for carrying the stone to the dumping spot. The wagons had flap bottoms, through which the stones were dropped. As soon as the waves had consolidated the mass, and brought the slopes to the natural "angle of repose," the superstructure, two walls enclosing a hearting of rubble masonry, was built. The seaward face of the wall is protected at the foot by the large rubble covering the top of the mound.

Holyhead Breakwater.

The year—1847—in which the Holyhead breakwater was begun also witnessed the commencement of the breakwater at Alderney, which is remarkable as being formed near the head in a depth of 133 feet below low water at ordinary spring tides. The superstructure, a wall 59 feet high, gave much trouble owing to settlements of the mound below and to the terrific pounding it received from large stones of the mound during storms. This breakwater cost £1,217,000, or about £200 for every lineal foot.

Alderney Breakwater.

Passing now to Ireland, we should notice the breakwater on the south side of Dublin Harbour. The foreshore (sea slope) of this was originally faced with granite blocks, the largest of which weighed 6 tons. These were gradually broken up and removed by the waves; so in 1862, Mr. B. B. Stoney replaced them with 50-ton concrete blocks, which sufficed until, in 1873, a storm pulled one out, moved it 30 feet, and turned it completely over. Determined to effect permanent repairs, Mr. Stoney prepared on

Immense Blocks at Dublin.

land the largest concrete blocks that have ever been transported in their complete condition. Each block measured 27 by 21½ by 12 feet, contained nearly 5,000 cubic feet of concrete, and weighed 350 tons. After being allowed to dry for ten weeks a block was lifted by a shears on a floating pontoon, carried to its site, and lowered on to the foreshore, where, until now, it has helped to protect the foreshore and sea wall most effectively.

What the Waves did at Wick.

For a really extraordinary example of the forces with which the engineer has to contend we may cite the dislocation of the superstructure of Wick Harbour. In 1871 the head of the superstructure was formed as follows: on the levelled top of the rubble mound a single course of 100-ton concrete blocks; then two courses of 80-ton blocks; and finally an 800-ton monolith of cement rubble, attached to the uppermost course of blocks by 3-inch iron rods. The whole mass—1,350 tons—was removed bodily by the waves, turned round, and dropped inside the mound; while the second course of 80-ton blocks was swept away like so many bricks. A 2,600-ton concrete monolith was substituted. Before it was two years old a storm shifted it and broke it in half!

Portland Harbour.

Portland Harbour is probably the largest of all purely artificial harbours. It has an area of well over 2,000 acres to the one fathom line, and includes 1,500 acres of five-fathom water at low tide. The harbour is bounded by the land and the famous Chesil Bank of shingle on the west and north-west, and on the south by the island from which it gets its name. In 1849 a rubble breakwater was begun, running from the island in a north-easterly direction, and beyond it a second and much longer detached mound bending sharply northwards. Between the two was left a narrow passage for ships. The mounds, completed in 1872, were formed by running stones down a ropeway from the Portland quarries to a staging erected on the line of the breakwater, along which they were moved in trucks for dumping. The work was done by convict labour.

To render the harbour fit for strategical purposes and able to protect warships from torpedo attack, two large additional breakwaters, pointing south-eastwards from the northern end, have been added. The Bincleaves breakwater, 1,550 yards long, reaches out from the mainland. A second and isolated mound lies between it and the seaward extremity of the old island breakwater, there being a 700-foot passage at each end. For these newer works the stones quarried at Portland were delivered down a rope incline into barges, which dumped them on the line of the mounds, as had been done many years before at Plymouth. On the top of the mounds, which have a bottom breadth of 285 feet and a maximum height of 57 feet, is a wall of ashlar about 20 feet high. The amount of material used in the 2¾ miles of breakwater was enormous.

Algiers.

The Algiers breakwater is an interesting example of a mole built up largely of concrete blocks thrown in at random. The older part of the mole is composed of 25-ton blocks heaped up on the sea bed. The newer portion was constructed at less expense by bringing a flat rubble mound to within 33 feet of low-water level, and depositing the blocks on this base. The use of random blocks is economical, since less labour is required, and, as the spaces between the blocks equal one-third of the total volume of the heap, less material; but a mound so constructed would not be suitable for sites where the waves are exceptionally violent.

The new defensive harbour at Gibraltar has an area of about 440 acres. It is protected by two moles running out from the shore and by

a detached mole which occupies about three-quarters of the distance between the extremities of the shore moles. The "island," or detached breakwater, consists of a vertical wall of large concrete blocks built upon a rubble mound formed in from 45 to 65 feet of water. As it was impossible to connect the site of this breakwater with the shore, the engineers adopted a novel plan for providing a foundation from which the Titan cranes could commence their task of block laying. A huge steel caisson, 101 feet long at the bottom, 74 feet long at the top, 33 feet wide, and 48½ feet high, was built in England, taken to pieces, and shipped to Gibraltar, where it was reassembled, towed to its position at the centre of the mole, and sunk on to the rubble mound. The interior was then filled in gradually with concrete, and eventually an artificial island, weighing 9,000 tons, came into existence. On it were erected two Titans, which worked away from one another, laying the blocks which were brought up by barges as required.

Gibraltar.

An Enormous Monolith.

BREAKWATER AT VERA CRUZ, SHOWING "RANDOM" CONCRETE BLOCKS TO PROTECT THE WALL.

At Zeebrugge a breakwater 5,000 feet long has been built recently to protect the entrance to the Bruges Canal. The outer part of the breakwater, which has to bear the brunt of a storm, is composed of huge concrete monoliths weighing about 4,400 tons each, and measuring 82 feet in length, 29½ feet in width, and 28¾ feet in height—probably the largest series of concrete blocks ever made. On

A Novel Process.

account of their huge size and weight they could not be transported complete to their final positions, nor was it convenient to mould them *in situ*. The engineers therefore adopted the following procedure: In the inner harbour iron caissons of the same dimensions as the blocks to be were put together. They had an inner skin some feet distant from the outer one, the two skins being brought together at the bottom to form a cutting edge. The space between the skins having been filled up with sufficient concrete to give stability, a caisson was towed out and sunk in its place by adding some more concrete, until the cutting edge had sunk well down into the clayey sea bottom. The central space was then filled in with concrete lowered by means of cranes and skips.

For the Newhaven and La Guaira Harbours the "sack block" system was employed. For this a special barge, with hinged bottom, is used. The bottom having been closed, a large sheet of stout jute sacking is arranged over it and up the sides of the central well. Concrete is deposited on the canvas and levelled until a sufficient thickness—from two to three feet—is attained, when the edges of the sacking are brought over the top of the mass and laced together. The vessel is moved to the dumping spot, and, on the bottom being opened, the sack and its contents are deposited. The concrete soon hardens. At La Guaira courses of 180, 130, and 70 ton blocks were laid, the largest blocks being at the base, and the size decreasing upwards.

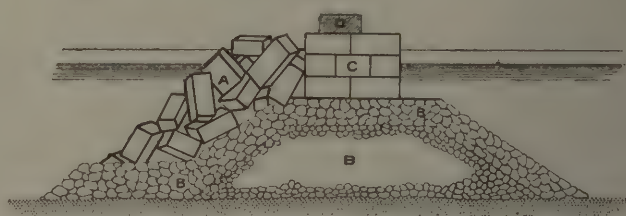
The Sack Block System.

Sack blocks were also used for the foundations of the new south breakwater at Aberdeen. This breakwater is an interesting example of mass concrete work. From the single course of sacks on the sea bed to low-water level at neap tides the structure is composed of large concrete blocks. These are capped by monoliths of concrete formed in place in wooden frames, and weighing from 335 to 1,300 tons each, according to their length along the line of the breakwater. Each monolith extends right across the breakwater.

Aberdeen.

At Vera Cruz, on the Gulf of Mexico, is one of the greatest artificial harbours in the New World. The coast-line here faces north-north-east, and originally was exposed to the furious "Northers," which did great damage to any shipping anchored in the port. Even slight breezes hampered seriously the transference of cargo from ship to lighter, or *vice versâ*. In 1882, James B. Eads, the designer and engineer of the St. Louis Bridge (Vol. II., p. 163 foll.), submitted plans for utilizing the coral reefs near the port as foundations for breakwaters which would create a secure harbour. Between that date and 1895 a small part of the total work required was done. In the latter year the contractors handed over the enterprise to Messrs. S. Pearson and Son of London, who completed it successfully during the following seven years. Three separate breakwaters had to be built on the north-west, north-east, and south-east respectively. The first of these was formed by depositing a rubble mound from a trestle, and capping it with a wall of 35-ton concrete blocks laid by a crane. On the seaward side this breakwater is partly protected by random blocks placed by a previous contractor. For the north-east mole a

Vera Cruz.



NORTH-EAST BREAKWATER, VERA CRUZ.
A, Random concrete blocks; B, rubble mound; C, concrete blocks in courses; D, concrete cap.

A CRANE SETTING 30-TON BLOCKS ON THE NORTH-EAST BREAKWATER, VERA CRUZ.

(By permission of Messrs. S. Pearson and Son, Ltd.)

rubble foundation was dumped from cars and barges, and levelled carefully by divers. This foundation is about 20 feet high, and is brought up to 10 feet below low water. Along its crest a Titan and two floating cranes laid sloping 35-ton blocks, a number of which were thrown at random along the exterior side. The breakwater has an average width of $97\frac{1}{2}$ feet and a length of 2,400 feet. It may be mentioned that the Titan crane, weighing 360 tons, was flung off the breakwater by a gale, but was recovered, and used for further harbour building.

The south-east breakwater, 3,070 feet long and 65 feet wide (average), was formed of rubble, capped with concrete blocks and mass concrete.

In addition to the moles, Messrs. Pearson built an inner protection wall, and by means of quays and piers converted Vera Cruz into a first-class artificial port, equal to any in the world, and equipped with every facility. The harbour has an area of 543 acres, and an average depth of 28 feet at low water. Six and a half million cubic metres of sand and 50,000 of rock were removed by dredges. The port works consumed 2,000,000 tons of stone and concrete. There are about $3\frac{1}{2}$ miles of piers and quays. The total cost is calculated at about £3,000,000 sterling.

DIVERS, DIVING-BELL, AND A LARGE GRAB FOR LEVELLING THE SEA BOTTOM.

Dover.

An even greater undertaking carried out by the same firm of contractors is the new Admiralty harbour at Dover, constructed during the years 1898–1909. It has an area of 610 acres, and is one of the largest artificially enclosed sea-water spaces in the world. The work to be done—shown on the accompanying plan—consisted of—(1) lengthening the old Admiralty Pier 2,000 feet; (2) reclaiming and excavating out of the cliffs an area 3,850 feet long by 250 feet wide; (3) building a 3,320-

foot breakwater at the east end; (4) building an island breakwater on the south, between the heads of the two arms.

PLAN OF NEW ADMIRALTY HARBOUR, DOVER.

The works marked in solid black have recently been completed by Messrs. S. Pearson and Son.

The form of structure adopted for the breakwaters was a wall between 50 and 60 feet wide at the base, built on the sea bottom, and tapering upwards gradually to a height varying between 80 and 90 feet. For all the walls large concrete blocks, weighing up to 42½ tons, were used, those set on the sea faces being covered with granite ashlar built up inside the moulds before the concrete was poured in.

The contractors began operations on the Admiralty Pier extension, and cutting away the chalk cliff along the easterly half of the strip of shore included in the harbour. The chalk, detached by gangs of men roped together for safety, was dumped in the sea behind a retaining wall of 3-ton blocks. Eventually ample room was secured for block-making yards, workshops, and storehouses.

As a preliminary to construction work, the shore end of the great gantries to carry the 100-ton Goliath cranes had to be built by driving in great iron-shod piles, 100 feet long and from 18 to 20 inches square, in groups of six, three on each side of the line of the future blockwork, and by connecting the groups with horizontal girders and bracings. The girders were covered with a heavy timber flooring as a base for the Goliath and block-truck tracks. Oregon pine piles were used in the first instance, but replaced subsequently by sticks of Tasmanian blue gum, which, being heavier than water, does not float when detached, to the danger of shipping, and is immune from the ravages of the sea-worm.

The Goliath Gantries.

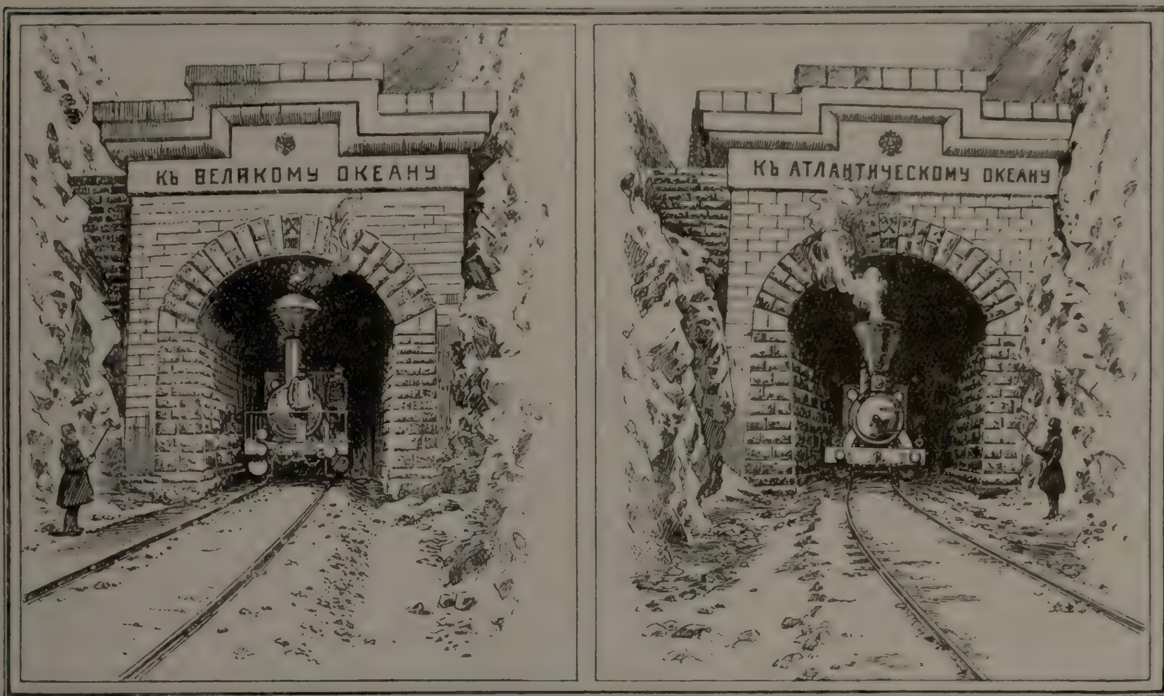
When a gantry had been advanced sufficiently a Goliath was erected on it, to work the grabs and breakers used for levelling roughly the sea bottom. Behind this crane followed a second for the diving-bells, under cover of which divers levelled the surface accurately. A succeeding crane did the under-water block laying, the crane-men working in accordance with signals sent up by divers, and a fourth placed the above-water courses. This system made for general rapidity of progress, as all the stages of construction proceeded simultaneously when weather and tide permitted. It is interesting to note that the Admiralty Pier extension was built at more than six times the speed of the old pier —600 feet in a year compared with about 90 feet.

To save time, the contractors wished to build the island breakwater independently of shore connections; but, owing to difficulties in securing a starting-point in the open sea, it was found necessary to prolong the gantries of the east arm and bring up the cranes and material over that arm, closing temporarily the south-east entrance to the harbour.

About 64,000 blocks, weighing together 1,920,000 tons, have been used in forming the breakwater walls. To get the grand total of about 3,000,000 tons we add the blocks for the retaining wall of the reclamation and the horizontal apron blocks laid on the seaward side of the breakwaters. The excellent views which, by the courtesy of Messrs. S. Pearson and Son, we reproduce, will give the reader a better idea of the constructional operations than could be conveyed by words.

A CONVICT GANG AT WORK BUILDING THE TRANS-SIBERIAN RAILWAY.

THE TRANS-SIBERIAN RAILWAY.



ENTRANCES TO TUNNELS IN THE TRANS-BAIKAL SECTION OF THE RAILWAY.

The words "TO THE GREAT OCEAN" appear over the western portal, "TO THE ATLANTIC OCEAN" over the eastern portal.

BY T. FLETCHER FULLARD, M.A.

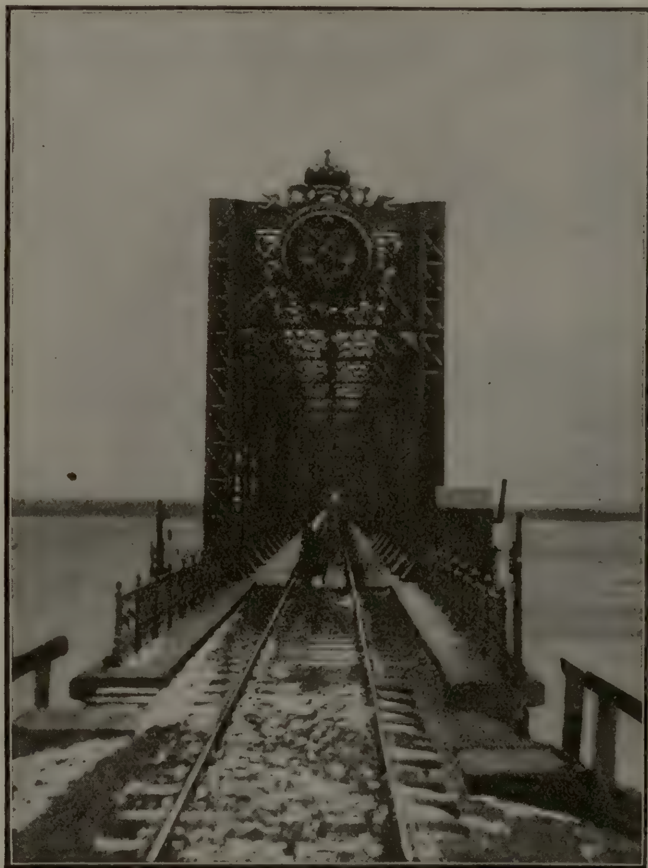
An Account of the Longest Railway in the World.

AMONG the incidents in the Crimean War was the unsuccessful attack by a British squadron upon the fort of Vladivostok. When, a few years later (1860), China ceded to Russia the Littoral Province —the Ussuri and the valley of the Amur—the empire of the Czar was established still more firmly on the shores of the Pacific. From that time onwards various schemes for connecting these Far Eastern dominions with European Russia by a railway were successively brought forward, discussed, and allowed to lapse. Continental railway building was a science comparatively in its infancy; and for long the vast distances and the colossal expense involved, added to the doubtful success of so enormous an undertaking, proved insuperable obstacles.

Early Schemes.

The earliest project is credited to an English engineer named Dull, who suggested a horse-drawn railway from Nizhni Novgorod on the Volga to the Pacific—not such a wildly chimerical idea after all, considering the plenty and excellence of horse-flesh in Siberia. Then various private companies offered to lay steam tracks across the plains; but they met with scant encouragement, the would-be promoters

being for the most part foreigners. Yet the main idea was constantly under consideration, and in 1875 an Imperial Commission reported that Vladivostok ought to be connected by rail with the valley of the Amur. Again, fifteen years later, the Minister of Ways of Communication reported to the Czar that "the Ussuri Railway ought to be laid down with all possible speed." On the margin of this report Alexander the Third wrote with his own hand: "It is urgent to begin laying down this track at the earliest possible moment."



THE GREAT BRIDGE OVER THE VOLGA.

These words settled the question. On March 29 (new style), 1891, an imperial rescript was addressed to the Czarevitch Nicholas (the present Czar), stating that the order had been given "to build a continuous line of railway across Siberia to unite the rich Siberian provinces with the railway system of the interior." This momentous decree was promulgated by the prince upon his landing at Vladivostok from his Eastern tour. On the 31st of the following May, surrounded by a crowd of labourers and convicts standing ready with picks and shovels, he turned the first sod of a railway which was to run for 4,731 miles. Since that date events in the Far East have marched with startling rapidity, and the share taken therein by the Great Siberian Railway, as both cause and effect, has been all-important.

A Railway commanded.

The Russian peasant is slow, slothful, and improvident, but a man of indomitable perseverance withal. These attributes may be justly ascribed to the influences of the land in which he lives. The distances are so great, the monotony so unvarying, in a country where six months of travel scarce serves to change the scene, that haste and speed seem wasted effort; whereas patience and endurance are indispensable for mere existence. Siberia itself, apart from the other Russian territories in Europe and Asia, has an area of 7,824,056 square miles. Its scanty population is about 7,200,000 souls—less than one to the square mile. The inhabitants are mainly grouped upon the natural line of travel, in the towns which have grown up on the great waterways and are now strung together upon the railway. They are mostly settlers and exiles from European Russia, or the descendants of exiles, both political and criminal.

Inhabitants of Siberia.

Siberia is divided into the Governments of Tobolsk, Tomsk, Irkutsk, and Priamur, the

last-named being the region between Lake Baikal and the Pacific Ocean. Western Siberia extends from the Ural Mountains to the Yenisei River, in a vast plain of good agricultural soil in the middle and southern parts, destined, many people think, to become the greatest granary of the world. Eastern Siberia, thrice as large, is mostly hilly or mountainous. The climate is severe, with extremes of temperature, and abrupt changes from winter to summer and the reverse.

Features of Siberia.

From St. Petersburg to Vladivostok the total distance is 5,800 miles; to Port Arthur, 6,000 miles. Leaving the modern capital, the traveller reaches Moscow in eleven to twelve and a half hours by an almost dead straight line of 404 miles. From Moscow the route lies through a rich country dotted with some of the most prosperous villages of the empire. Samara is reached in thirty-four hours. This town lies in the famous "black earth" region, known to the Russians as the "Tchernoziom," peopled by a strange medley of races and tribes. At this point comes in the railway from Orenburg, bringing the trade of Khiva, Bokhara, and Central Asia.

Distances.

From Samara the line runs north-east through a flat country to Ufa (95 miles), and after passing Zlatoust ascends the wooded slopes of the Ural Mountains, the great mining region of European Russia. At the highest point of the range a triangular stone pyramid, bearing on one side the word "Europe," and on another "Asia," marks the frontier. The line follows the curves and contours of the gentle slopes with few cuttings and no tunnel whatever throughout its course, and so slides down to the important junction of Tchelyabinsk, the actual starting-point of the Siberian trunk line, and also the terminus of a railway now running northward through Ekaterinburg towards Archangel on the White Sea.

The problem which faced the Russian engineers and financiers in 1891 was to connect, by means of an uninterrupted line of rails, this station of Tchelyabinsk with Khabarovsk on the lower Amur, and so with the port and fortress of Vladivostok. The work naturally divided itself into sections presenting widely different degrees of engineering difficulty. The great plains of the west lend themselves peculiarly to railway construction; but half way, roughly speaking, is the very formidable obstacle of Lake Baikal, throwing its full length across the path. East of this lake the broken valley of the Amur promised trouble enough, a promise which still holds good. The Vladivostok-Khabarovsk section was fairly simple, and eventually the difficulties of the Amur valley were turned, as will be seen, by diverting the track across Chinese territory, which afforded easy going.

The Task.

During the three last years of Czar Alexander's reign much progress was made in mapping and surveying the route, and a scheme for laying down the line in sections was formulated. Thus shortly after his accession in 1894 the Czar Nicholas, who retained his post of president of the committee directing the railway, was able to say to the members: "With your assistance, I hope to complete the construction of the Siberian line, and to have it done cheaply, and, most important of all, quickly and solidly."

Surveying.

The work was now vigorously put in hand; but from the outset the enormous sums of money required, and the fact that the scanty population and backward state of agriculture in Siberia rendered a return of profit very problematical, compelled the Imperial Commission to keep the initial outlay as low as possible. European methods of railway construction had to be modified very greatly. It was decided that a single track should be laid down, with a through carrying capacity of only three

Specifications.

pairs of trains a day. Light steel rails, weighing 18 lbs. to the foot, were held to be of sufficient strength. The bridges, excepting those across the great rivers, were to be of wood. The width of the embankment was fixed at 2·35 fathoms, instead of 2·6 fathoms, which is the normal width, a Russian *sazhene*, or fathom, containing 7 feet. On the steepest gradients and sharpest curves considerable deviation from the generally accepted rules was allowed. The sleepers were to be laid on a thin bed of ballast, and all station buildings were to be of the simplest construction. Thus in the beginning one part at least of the Czar's aspirations was heavily discounted. Worse was to follow. The work being let out by contract, the corruption and peculation so rampant in Russia got a golden opportunity. Everywhere the Government was plundered most flagrantly, and millions of roubles found their way into the pockets of officials leagued with the contractors. For instance, in many places the width at the top of the embankment, which by contract should have been 15 feet, was reduced to barely 11 feet. Knowledge of facts like these led foreign critics to say that the Siberian Railway could not be relied upon in the hour of trial, especially as the line was a single track. These views have been fully borne out, for the traffic has been repeatedly stopped by "wash-outs," landslips, and accidents to the permanent way. As late as May 1908 the manager reported to St. Petersburg that an interruption of the traffic was due at that time to the permanent way and embankment having been washed away for a distance of 3½ miles, and that one thousand men had been set to work to repair the damage. One cannot avoid the reflection that the patriotic resolve of Czar Alexander to employ none but Russian brains and hands upon his great undertaking is more to be applauded than admired. Perhaps he might have adjusted his wishes, however, could he have foreseen how political engineers were to force the pace. These initial mistakes, and the heavy price that has since been enacted for them, must nevertheless compel great respect for the dogged per-

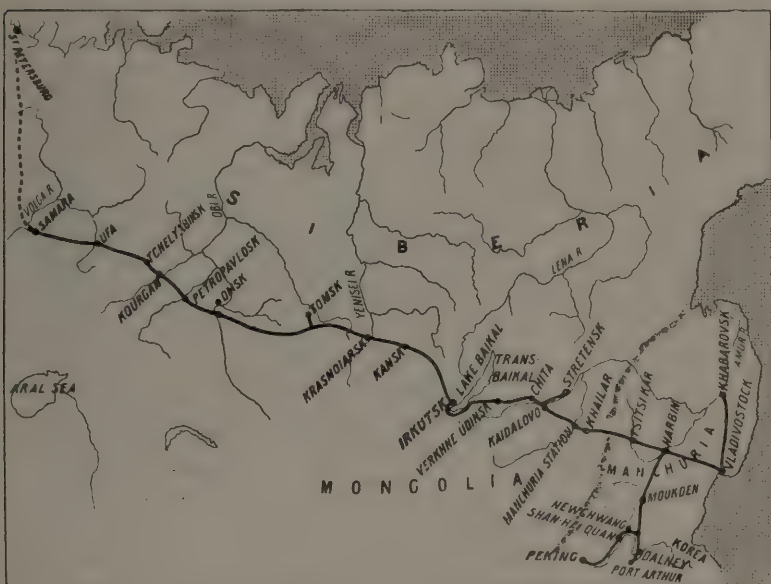
AN EXPRESS CROSSING THE STEPPES IN WINTER. (*Photo, Locomotive Publishing Company.*)

Corrupt Officials.

severance which ultimately won success at the moment of the nation's sorest need.

Though the trains for the long eastward journey are made up at Moscow, the actual starting-point of the Siberian Railway is, as has been said, Tchelyabinsk, 1,372 miles from Moscow, and about 200 miles beyond the frontier. The trunk line, as originally planned and laid down, runs from Tchelyabinsk to Stretensk on the Amur, a total distance, including the width of Lake Baikal, of 3,244 miles, and

Sections of the Railway.



MAP OF THE TRANS-SIBERIAN AND MANCHURIAN RAILWAYS.

was divided into the following sections, from west to east: The West Siberian, to the river Obi, 886 miles; the Mid-Siberian, from the Obi to Irkutsk, 1,144 miles; the Irkutsk, to Baikal, 43 miles. From Stretensk the journey was at first continued by steamer down the Amur to Khabarovsk, and completed by the Ussuri Railway to Vladivostok, 481 miles.

From the western starting-point right away to the Baikal the engineering aspect of the route is practically uniform, and presented a minimum of difficulty. The gently rolling steppes and the great plain lend themselves, as has been said, to railway enterprise, and the wonder is that the work had not been undertaken long before. There are but few cuttings, and the direction taken was the easiest that could be found. At first the track stood only a foot above the 150 feet of clearing on either side, and on the imperfect ballast the sleepers were laid, and the light rails spiked to them. From this brief description it is easy to realize that no great speed was possible—15 miles an hour the maximum—and that the rapidly growing traffic soon began to reveal the shortcomings of the line. The real difficulties were presented by the great streams, the Obi, the Irtysh, and the Yenisei, which, with their numerous tributaries, carry off the rainfall of the mighty mountain system of Central Asia to the Arctic Ocean, affording magnificent waterways as they cross the wide plains, and serving as invaluable feeders to the commerce of the railway. No less than 30 miles of bridges had to be constructed on this system, some of them of great length. The largest is that across the Yenisei, an iron six-span bridge of 2,520 feet, including one span of 420 feet. Work of this nature was well within the scope of Prince Khilkoff, Minister of Ways of Communication, a practical engineer trained in the workshops of England and America, with considerable experience of railway construction in the United States. Neither he nor his staff, however, had had much to do with tunnelling, so it was a particularly fortunate circumstance that no work whatever of this kind was needed at any point between Europe and the Baikal. After the Obi is passed, the country becomes hilly and wooded; but gradients and curves are always moderate, and

Great Rivers.

construction continued to be uniformly easy as compared with work on the same scale in other parts of the world. Beyond the Baikal, conditions became much more difficult. In the first nine years after the work was begun in May 1891 the rails were laid for a total distance of 3,375 miles, or at an average yearly rate of 375 miles. This was highly satisfactory, as very serious difficulties had been overcome, especially in Trans-Baikalia, where the work was stopped repeatedly by inundations, and the line washed away for long distances. With the threat of war with Japan driving them on, the Russians, it may be noted in passing, actually laid a part of the track of the Manchurian Railway at a rate of three miles a day.

Siberian Trains.

Leaving the heavy work about Lake Baikal and eastward for future consideration, we will review the western and central sections of the line. The trains which leave Moscow vary greatly in their composition. There is, first, the great Trans-Siberian express *de luxe*, affording the highest degree of comfort in travelling that can be found anywhere. Not only are sleeping and dining cars provided, but these contain bathrooms, a library, electric light, and every fitting which may solace the bored tourist, all unusually commodious, thanks to the 5-foot gauge. Then there are mixed trains of first, second, and third class coaches; others, again, of the inferior classes only; emigrant trains of fourth and even fifth class, little better than cattle-trucks; and, finally, numerous freight trains. Following its policy of settling the country by colonization, the Government attracts by offers of free land vast numbers of agriculturists from the poverty-stricken villages of Europe, and conveys them almost free of cost to their distant destinations. Naturally the accommodation *en route* is of the simplest quality, floor space and little else being provided. The fourth-class travellers enjoy the luxury of windows to their cars, the fifth class not even

ONE OF THE EXPRESS LOCOMOTIVES. (*Photo, Locomotive Publishing Company.*)

this. The convict trains, still sufficiently numerous, are said to be somewhat less comfortless. The Russian peasant's standard of comfort is, however, so low, that he appears to suffer little, if any, hardship while travelling in this style.

From the Urals to the Obi the far-reaching plain is broken only by marshes and salt-lakes, with an occasional cluster of snow - white birches. At every verst is a signal-box, each in sight of the next on either side, worked with little green flags by stolid peasants or good-conduct convicts. Red-painted stations break the monotony every twenty or thirty miles, and at every one a halt is made by the ordinary trains for tea, vodka, and food to be taken. There is always a buffet, and the provisions supplied are generally excellent. When the journey is to be resumed a bell rings thrice, and then the locomotive whistles thrice at long intervals. After the last whistle there is again a long wait before the train starts off slowly. After Tchelyabinsk the first important station is Kourgan, on the Tobol, a considerable distance from the town of the same name. In this region the Government has reserved a belt of land 67 miles wide alongside the railway for the exclusive use of colonists. Petropavlovsk, on the river Ichim, is next reached, a rapidly developing town, which again has been left more than a mile from its station. Crossing the great stream of the Irtysh by a six-span bridge, 2,259 feet in length, the line passes, still at a respectful distance, the large town of Omsk, the capital of its government.

Stations.

INTERIOR OF THE CHURCH CAR WHICH TRAVELS ON THE SIBERIAN RAILWAY.

Omsk railway station is one of the most important centres in Siberia. It contains over seventy railway workshops, a large locomotive shed, a great network of sidings, and the general stores for the railway. There are also a hospital, churches, and schools for the use of the railway men.

Important Towns.

With the crossing of the Obi, by a bridge 2,613 feet long, some 400 miles beyond Omsk, the central section of the railway is entered upon. For rather more than a hundred miles the line runs through a well-wooded, slightly hilly region lying between the steppes and the "Taiga," the impassable region of virgin forest, stretching away northwards to the verge of the Arctic zone. Skirting the northern spurs of the Altai Mountains, which separate Siberia from China, the route now has to traverse the Ala Tau and Saian Mountains, and here the work of construction began to meet with embarrassing

difficulties. The cost of the 1,186 miles between the Obi and Lake Baikal, though the first 367 miles was over open plains, amounted to £11,743,901, or £9,902 per mile. The principal towns on this section are Tomsk, the most populous town of Siberia and capital of the government of the same name, Krasnoiarsk, and Kansk. Tomsk, lying at the end of an inconvenient branch line 56 miles long, furnishes the most glaring instance of the official methods followed during the survey for the railway. The surveying engineers, it is well established, approached the Tomsk town authorities, and hinted that under certain conditions the main line would be laid to the town, but that possibly an alternative route might be chosen. The townspeople were given to understand that to secure the carrying out of the former project the usual "palm oil" must be forthcoming. The citizens refused, however, to be treated in that way, and the painful result of their independence was that the Siberian Railway passed nearly sixty miles south of their town. Again, when the question arose of laying down the connecting branch from the little settlement of Taiga ("In the wood") to Tomsk, the same "dispute" arose between the surveyors and the local people, and

LAYING THE RAILS OF THE SIBERIAN RAILWAY.

The Penalties of Independence.

the former took their revenge by allowing the line to approach Tomsk within two miles, and then taking it carefully round the town at an equal distance, to a terminus a couple of miles distant on the farther side. It would seem that no Siberian town of any importance was complaisant enough to escape punishment of this kind entirely. Perhaps Irkutsk is the most fortunate, for there the station is but on the other side of the river. Other towns generally have to use from one to three miles of road, and it must not be forgotten that in Siberia roads are no roads. Two or three feet of slush or dust take the place of road-metal when the frost is out of the ground.

From Taiga the line runs 300 miles through virgin pine-forests until Krasnoiarsk is approached. This is another important depôt, employing fifteen hundred workmen in the various shops and engine-sheds, while vast stores of railway material are kept there.

Krasnoiarsk is destined to play a great part in the future development of Siberia, for it is connected by an excellent river service during the navigation season with Yeniseisk, to which point on the Yenisei River sea-going steamers ascend from the Arctic Ocean. A mile and a quarter beyond Krasnoiarsk the Yenisei is crossed by a six-span bridge of 3,054 feet in length. From Kansk to Taichet, a distance of 105 miles, the line runs through immense coalfields, all waiting to be worked. After Taichet come another 100 miles of the Taiga, where the scanty population clings closely to the railway.

A WAYSIDE STATION.
(*From "The Real Siberia," by John Foster Fraser*)

The Central Siberian section of the railway ends on the bank of the Angara River, facing Irkutsk, 2,035 miles from Tchelyabinsk. Irkutsk, though not yet absolutely the largest, is certainly the richest town of Siberia.

A short section of 43 miles, containing a prodigious number of small wooden bridges, connects Irkutsk with the shores of Lake Baikal.

Lake Baikal.

This famous sheet of water, was long recognized as the "crux" of the engineers planning the Siberian Railway, and might have been designed expressly by nature to test their ingenuity to the utmost. The largest body of fresh water in the Old World, it is only exceeded in area by the Victoria Nyanza in Africa and one or two of the great North American lakes. With its southern head deeply embayed in impracticable mountains, it stretches its mighty length for 400 miles towards the Arctic circle. To turn its northern extremity was out of the question; while to build a railway round the southern end, where the mountains in many places drop sheer into 3,000 feet of water, was a task quite beyond existing resources. That this must be the ultimate solution was, of course, obvious, but meanwhile temporary methods of overcoming the difficulty had to be devised.

Travelling over the Lake.

The line of travel from the earliest times had lain across the lake—in summer by means of the boats of the period, in winter by sledges over the ice. The lake is ice-bound as a rule from December to April, and during that part of the year the bulk of the traffic used to pass. Transit by sledge only lasts three months, as, owing to unexplained reasons, for some weeks after the ice is thick enough to bear the weight there constantly appear fissures several feet wide and from half a mile to a mile or more long. When these fissures are frozen over others appear and cause considerable delay.

A "MIXED" TRAIN ON THE MANCHURIAN RAILWAY.
(*From "The Real Siberia," by John Foster Fraser.*)

As the grip of frost tightened, a track was marked out by pine trees stuck in the ice, and a contractor was engaged to keep the road in repair and in a safe state for the passage of the mails. A more dreary track than this 40 miles of frozen road it is impossible to conceive, and it may well stand for a type of the little path trodden by the hopeless bands of exiles, goaded by the whips of Cossacks, towards the deadly mines and prison-houses of Sakhalin and Kamchatka. Nor were the dangers of nature alone to be apprehended. So lonely a drive gave every opportunity to the wandering, escaped convicts and roaming outcasts to prey upon the travellers crossing the ice, and robbery and murder were frequent. Outrages increased in number with the augmented traffic resulting from the arrival of the Siberian rail-head at Irkutsk and the shores of the lake. Here is a typical case. A gang of convicts marching across the ice observed traces of blood upon the snow. Examination led to the discovery of the body of a baby girl buried in the snow, but still alive. Inquiries proved that a sledge-driver of bad reputation had set out a few hours previously from the south-eastern shore of the lake to convey two poor women, each of them accompanied by two little children. This wretch had long been under suspicion, for he had been known on several occasions to set out with a passenger to cross the lake, and to reach home alone long before he could have had time to make the return journey. Further search revealed the bodies of the two women and three children buried in the snow, where the brutal driver had left them after beating them to death with his whip. Until the Circum-Baikal line should be undertaken and completed there was no alternative to the use of sledges for crossing the lake during the quarter of the year this method was available; but the joint difficulties of the open water of summer, subject to terrible storms during which waves are raised to the height of six and seven feet, and the rotten ice of spring and winter, were met by a remarkable combination in one frame of a huge ice-breaker and steam-ferry, equal to conveying an entire train and at the same time forcing its way through ice up to 3½ feet in thickness. An order was given to the firm of Sir W. G. Armstrong, Whitworth, and Co., of Newcastle, to build the ice-breaker *Baikal*, which was taken out in parts and put together, under the superintendence of a Sunderland engineer, at the village of Listvenitchaia by Russian workmen, drawn mainly from St. Petersburg, and acquainted with shipbuilding. The carrying through of this difficult enterprise has been described already in a very interesting article. (See Vol. i., pp. 65 foll.)

The "Baikal."

The *Baikal* proved a complete success, and led to an order for a second vessel of the same type, but of smaller size, the *Angara*, which also was taken out in sections and constructed on the lake. The cost of the two ice-breakers, of the stages for embarking trains, and of the breakwaters to provide shelter from storms, amounted to £596,250. This large outlay has been well justified, for, though their occupation as train-carriers ceased upon the opening of the Baikal Ring Railway, the two ice-breakers have been extremely useful in assisting the navigation on the lake.

Trans-Baikalia.

The Trans-Baikal section of the railway took off from the landing-stage at Missovaya on the south-eastern shore, having for its objective Khabarovsk on the river Amur. Political events profoundly modified the original scheme, and the main line halted abruptly at Stretensk, on the river Chilka, 686 miles from Missovaya, and 4,055 east of Moscow. Thence the journey has to be continued to Khabarovsk by steamer down the Chilka and the Amur, which forms the boundary between Siberia and the Chinese province of Manchuria. At Khabarovsk the frontier turns sharply south-

ward, defining a broad belt of Russian territory between Manchuria and the coast. At the southern end of this maritime province lies Vladivostok, the "Mistress of the East," and the real terminus of the Siberian Railway. The construction of this section presented far sterner physical difficulties than had been faced hitherto. To cross the Yablonoi Mountains the line has to climb 3,412 feet. The formidable gradients required thorough methods and heavy rails, the last supported by ties set in cement. Cuttings are numerous, and, owing to the intense cold of this high region, the frost-bound earth had to be blasted with dynamite and all masonry to be built in warmed shelters. In mild weather floods gave constant trouble.

THE STATION AT BOGOTOL.

Quick Work.

Rail-head reached Stretensk in July 1900, a little more than eight years from the start at Tchelyabinsk. The line had leapt forward at record speed. Omsk was reached in 1895, after three years' work; Obi in 1896; Irkutsk in 1898. By the same date the Ussuri section had been completed, making an average rate of construction, as has been said, of about a mile a day.

The Manchurian Railway.

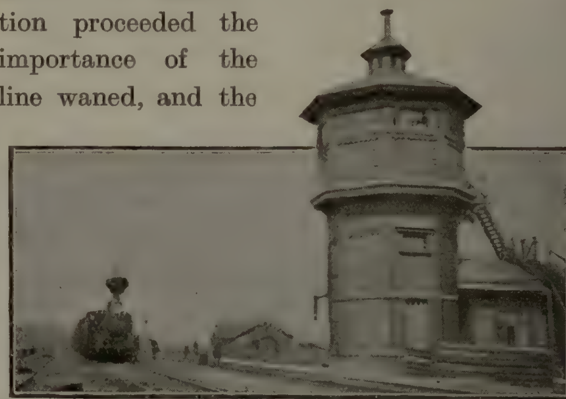
The unlooked-for event which had pushed the Amur Railway project into the background was the war between China and Japan in 1894-95. An immediate result of this conflict was the "lease" by China to Russia of Port Arthur and Ta-lien-wan (the latter place being re-named Dalny—that is, "Far off"), carrying with it the right to lay down railways through Manchuria, to bring these seaports into direct communication with the Siberian system. This concession was of inestimable value to Russian ambitions. Surveys were made promptly to establish the most suitable route for a track to connect the Trans-Baikal Railway with Vladivostok. The surveyors selected a line leaving the main track at Kaidalovo, 72 miles east of Chita, and running thence in a south-eastern direction across Mongolia and Manchuria to Tsitsikar and Harbin, and from Harbin almost due east to join the Ussuri Railway at Nikolskoye, 68 miles north of Vladivostok. This line was called officially "The East Chinese Section." It may be mentioned that, in true Russian fashion, the station of Tsitsikar lies 21 miles from the town of that name. The length of

this section is 1,200 miles, 890 of which lie in Chinese territory. Construction was begun forthwith from both ends, and pressed forward with a haste that became more and more feverish as the political situation grew more critical. Thousands of Chinese, Manchus, and Koreans, the last-named wearing their white clothes and using curious little shovels and very small baskets to move the earth, were employed under Russian overseers. Taught by experience, the engineers laid down a temporary contractors' line and a well-built permanent way alongside it.

This line constituted the original concession; but meanwhile the Russian Government, assuming for the nonce the transparent *alias* of "The Russo-Chinese Bank," had obtained powers to run a branch southwards from Harbin to Dalny and Port Arthur, and pushed it forward with all possible speed. These lines, which figured so largely in the Russo-Japanese War, run for the most part through very desolate regions, including a portion of the Gobi Desert, and were most jealously watched and protected by the constructing power. Chinese and Manchus were not allowed to live within twenty miles on either side of the track. A large force of mounted Cossacks was quartered in squat, whitewashed "posts" all along the railway. Beside every "post" rose a high wooden tower, from the top of which a lookout could be kept for bands of Chun-huses, or marauding Manchus, the pest of the country.

The northern line is still in Russian hands, and remains the direct route to Vladivostok. The branch from Harbin southwards has passed into other keeping. It will be remembered that the heavy fighting of the Japanese war developed upon its lower stretches, and how, during the siege of Port Arthur, the Russian forces were steadily pushed backwards from Liao-Yang and from Mukden, and at the conclusion of peace were lying entrenched in defence of Harbin, the capture of which junction would have entailed the fall of Vladivostok.

The Ussuri Railway, begun in 1891, was at first hurriedly, and therefore badly, laid down. As construction proceeded the importance of the line waned, and the first through train from Khabarovsk to Vladivostok—a distance of 483 miles—did not run until September 1897. The line has no outstanding features of interest. Laid along the narrow valley of the Ussuri River, it taxed the engineers only in the making of large iron bridges, notably those across the Kia, Khor, and Bikin. Here, as in West and Central Siberia, an excellent system of water-carriage was an auxiliary of inestimable value, for it allowed work to be carried on in several separate sections at the same time, and also relieved the through track of the conveyance of much railway material.



A WATER TOWER ON THE SIBERIAN RAILWAY.
(From "The Real Siberia," by John Foster Fraser.)

The Ussuri Railway.

Despite the expenditure of energy and money lavished in driving through the Far Eastern lines against time, the Russians never lost sight of the supreme importance of proceeding with the construction of the Baikal Ring Railway. The tremendous difficulties confronting the engineers on this part of the route have already been alluded to. A start was made in 1899 on both shores of the lake, but the two sections were not joined until Sep-

Baikal Ring Railway.

tember 25, 1904, when Prince Khilkoff himself took the first train of seven cars over the western section from the Baikal station near Irkutsk to Kultuck, 57 miles away. The eastern section, from Kultuck to Missovaya, is 106 miles in length. Both sections were finished at that time, and the station buildings were completed, though much work remained to be done at various points owing to the extremely varied character of the region traversed by the line. In the first sub-section of the western part the numerous valleys gave the surveying engineers a freer hand in deciding the route, but in the second sub-section the rocky shore of the lake had to be followed. Thus a great deal of tunnelling and blasting was inevitable, work for which the Russian labourers were not adapted by experience or training; so the Czar's restriction as to the employment of foreigners was waived, and large numbers of Italian workmen and navvies were engaged. Six miles from the start, after a marshy region, followed by a stretch of sand, had been passed, a rocky headland, coming down to the water's edge, had to be cut through for a distance of 1,100 yards. From the twenty-first mile to the thirty-first the mountains recede, and the line passes along an undulating terrace, and is laid at some distance from the lake, which it rejoins at the forty-first mile.

Heavy Tunnelling.

In the western section the contractors had to build thirty-three tunnels of a total length of 7,830 yards, and two hundred bridges and viaducts, with cuttings 95 yards deep in places—work necessitated by a succession of headlands, ravines, and inlets. To add to the difficulties, the stone was found to be unsuitable for tunnel-making, and the bore had to be lined with masonry of great strength. On each middle stone of the tunnel arches are carved an axe and an anchor crossed, while below the coping of the entrances one sees in big letters the words, at the western end, "To the Great Ocean," at the eastern, "To the Atlantic Ocean."

Labour Difficulties.

The total cost of laying down the Ring Railway (up to the late summer of 1904) was £5,678,206, or £34,906 per mile. Considering the vital importance to Russia of having the line laid down as speedily as possible in view of her political designs in the Far East, it seems strange that greater care was not devoted to carrying out this part of the work. In the first place, the work was let out to contractors. Probably this departure from custom was advisable under the changed conditions, but the contracts were loosely drawn, and allowed subletting, a fruitful cause of dispute and delay. Some of the contractors showed great indifference and neglect, and their shortcomings gave rise to frequent accidents and loss of life, easily avoidable by the exercise of ordinary care and control. The injuries, fatal and otherwise, were out of all proportion to what they should have been under usual conditions, even taking into consideration the enormous quantities of rock which had to be removed by blasting—400,000 cubic fathoms for the tunnels, and 461,700 for the permanent way. The men employed were in the main a wild and lawless set, among whom the Jewish pedlars of vodka, or white rye brandy, did a roaring trade. Dynamite in such hands spelt disaster. The Russian Government, hard pressed by the Japanese in Manchuria, had to resort finally to the costly expedient of offering premiums to the contractors for rapid work.

In laying down this line round Lake Baikal the engineers turned to account in two ways the experience gathered in building the main line from Tchelyabinsk to Irkutsk. First, they used rails weighing 72 lbs. to the yard instead of the light metals of 54 lbs. which were held sufficient for the traffic across Siberia. Second, due care was exercised in regard to curves and gradients. Thanks to the opening of the Ring

Railway, and the fact that numerous sidings had been laid all along the other sections, Prince Khilkoff was able forthwith to increase to seventeen the number of trains running daily from Europe to the seat of war. It is no exaggeration to say that the success of this piece of engineering was one of the principal factors which enabled Russia to conclude a disastrous war with a not dishonourable peace.

Under circumstances thus impressive did the dream of the Czar Alexander become a reality. The remotest confines of his realm were linked together by an uninterrupted band of steel, stretching from the German frontier to the waters of the Pacific. Much remained to do, for Siberia still stood but on the threshold of civilization, and many millions have since been spent upon the reconstruction of the main line alone.

COSSACKS GUARDING THE LINE.

(From "The Real Siberia," by John Foster Fraser.)

The Railway of To-day.

Settlers and traders are still pouring into Siberia almost as fast as trains can be found to take them, and already its agricultural produce, including butter and eggs for our breakfast tables, has established a place in the British markets. Our Japanese and Chinese mails now cross Siberia, with a considerable gain in time over the "All British" route *viâ* Canada. To-day a traveller to the Far East may take his seat at Ostend in one of the sumptuous *wagon-lits* of the Trans-Continental express, and not have to change his carriage twice before he descends at Vladivostok. Over the Siberian line, with its now well-ballasted and well-graded track, the commodious broad-gauge coaches will carry him as smoothly, though possibly not quite so safely, as in England.

Train Robbers.

An element of peril always associated with railway travel in lonely lands—to wit, the "holding-up" of trains by armed banditti—has to be apprehended in Siberia as elsewhere; but considering the generally disturbed condition of Russia during the last few years, outrages of this kind have not been conspicuously frequent. One such occurrence upon the Siberian line may be mentioned. As recently as August of last year armed robbers removed the rails for sixteen yards at a deserted spot near Omsk. The next train that came along was wrecked. The robbers fired upon the train when it left the metals, but were kept at a distance by the fire from the soldiers travelling on board as guards, until help arrived from Omsk, when they were put to flight without having effected their purpose of pillaging the mail-van, which they knew to contain a very large sum of money and other valuables. American operators would probably have proved themselves more skilful and successful.

The Future of the Railway.

The forecast of the Russian Government that when the Trans-Siberian line was in full working order the journey from London to Shanghai would be reduced to fifteen or sixteen days has been substantially realized. This railway affords the shortest and cheapest route from Europe to China and Japan, and

the promise is held out that it will eventually reduce the journey from England to Australia to some twenty-two days. As a commercial undertaking it is proving eminently successful; and when, if ever, honesty in public administration is developed as a Russian virtue, the system must become a national asset of incalculable value. Mid and Eastern Siberia, as well as the Ural district, are known to be among the most richly mineralized regions of the world, thick seams of coal and deposits of gold, both alluvial and quartzite, lying ready to the miner's pick. The agricultural outlook has already been touched on. To aid and supplement the railways in the task of gathering the lavish gifts of nature, there is already in existence a magnificent network of waterways, both natural and artificial, soon to be greatly improved by the construction of further canals, some of which, as already projected, will be works of the first magnitude. Without doubt, engineering as applied to ways of communication has a mighty future before it in Siberia and its physical complement, European Russia; and just as this vast expanse forms the major part of the greatest land mass of the world, so doubtless will it eventually become the scene of the grandest, in their different forms, of the achievements of the constructive engineer.

A TRESTLE BRIDGE IN THE "TAIGA" OR FOREST COUNTRY.

THE SPILLWAY OF THE NEW CROTON DAM. (*By courtesy of the "Scientific American."*)

Its outer surface is stepped to break the fall of the water.

THE NEW CROTON DAM AND RESERVOIR. (*Photo, P. P. Pullis.*)

The Dam is, next to the Great Pyramids of Egypt, the largest masonry structure in the world. It impounds 32,000,000,000 gallons of water.

THE WATER SUPPLY OF NEW YORK CITY.

BY JOHN GEORGE LEIGH.

ON June 21, 1907, on the side of one of many mountains soon to be perforated by a mammoth aqueduct, Mr. M'Clennan, Mayor of New York, cut the first sod of perhaps the greatest municipal engineering work ever undertaken.

The enterprise in question is the third of a series, all designed, within the comparatively short period of seventy years, with a single object—that of furnishing New York with a reliable and, in the estimation of its population, sufficient water supply.

Reasons for New York's haste and anxiety to secure a further source of water supply will be found in the city's geographical position, its rapid and continuous growth, and, it must be added, its people's ungoverned and apparently ungovernable wastefulness. Shut in on the east by the Atlantic Ocean, New York is prevented by the laws of New Jersey from tapping any near source of supply on the west. To the east of the Croton watershed is that of the Housatonic River, capable of yielding an abundance of excellent water; but this is in another State, Connecticut, and therefore excluded from consideration.

New York's Demand for Water.

The present population of Greater New York is estimated at four and a half millions, and the average annual growth is 115,000. This means, if the same increase is continued—and of this there seems every likelihood—that the population at the end of 1915 will be 5,260,000, and its water consumption 700,000,000 gallons a day, or more than 200,000,000 in excess of the present available supply.

Growth of Population.

This latter is very largely derived from the watershed of the Croton River, situated about 35 miles north of the city, and having an area

of 360 square miles, exceeding in size therefore the county of Middlesex. Previous to 1842 the citizens of New York had to depend for water on public wells situated at the street corners, and on a supply obtained from a well in a thickly-populated district, pumped by the Manhattan Water Company into a small reservoir, and thence distributed through hollow logs laid in some of the principal thoroughfares.

The First Croton River Project.

The first effective step towards direct municipal control was taken in April 1835, when a plan for bringing water from the Croton River was submitted to the popular vote, and carried by an overwhelming majority. Work on the project was begun two years later and continued until 1842, when water from the Croton was distributed to the city from a reservoir, the site of which is now occupied by a great public library, built on Murray Hill, fronting Fifth Avenue and 42nd and 40th Streets.

Judged by mid-nineteenth century standards, the achievement was one of considerable magnitude. It involved the construction across the Croton River, at a point where the latter was 120 feet wide, of a dam 55 feet high above the foundations. Behind this was formed a lake, covering an area of four hundred acres, with a storage capacity, for a depth of six feet, of 600,000,000 gallons. The most serious and troublesome part of the work, however, was the aqueduct. This, for a distance of 38 miles, was built entirely of masonry, with the exception of two sections crossing the Harlem River and what was known as Manhattan Valley.

MAP SHOWING THE ROUTES OF THE OLD AND NEW CROTON AQUEDUCTS, THE BRONX RIVER PIPE LINE, AND THE WATERSHEDS OF THE CROTON, BRONX, AND BYRAM RIVERS, WHENCE NEW YORK DERIVES ITS PRESENT WATER SUPPLY.

The First Croton Aqueduct.

Of these, the first was long regarded as a masterpiece of engineering, for, as chroniclers of the time remind us, with many expressions of admiration, the river was crossed by fifteen arches, seven of 50 feet span and eight of 80 feet, the greatest height from foundations to the top of the masonry work being 150 feet. Over this bridge, for a length of 1,450 feet, the water was carried in cast-iron pipes. In crossing Manhattan Valley, where the aqueduct was carried on a siphon, iron pipes were also used.

In some places, to avoid deep cuttings, the aqueduct was built in tunnels. Sixteen of these, varying from 100 feet to 1,260 feet in length, were excavated, the total amount of rock removed being 400,000 cubic yards. To us to-day this seems a small matter; but it must have been a difficult task seventy years ago, when gunpowder was the only explosive employed, and the holes had to be driven by chisel and hammer to an average depth of

two feet. The receiving reservoir, situated between 79th and 86th Streets, covered nearly thirty-one acres, and had a capacity of 180,000,000 gallons. The total cost of the aqueduct, including land and interest on water stock, amounted to about £2,500,000.

In 1849 the State Legislature created the Croton Aqueduct Department, giving it full charge of the city's water supply. The new authority at once found itself faced by difficulties, caused by constantly recurring leakages due to poor material and workmanship, and by continued demands for increased supply. When the aqueduct was constructed, a daily supply of 30,000,000 gallons was contemplated, and deemed ample even for a distant future. This estimate, however, had not sufficiently taken into account two factors—the irrepressible wastefulness of the population, and the latter's phenomenal growth.

Second Pipe laid.

The first step taken to meet the increasing demand was to lay an additional pipe, 7 feet 6½ inches in diameter, which brought the capacity of the aqueduct up to 60,000,000 gallons per day. This work was completed in 1861, and was followed by the construction of a large reservoir in Central Park, having a storage capacity of nearly 1,000,000,000 gallons. Then came, in 1864 and 1865, great droughts, which led to the building of another dam, now known as Boyd's Corner Reservoir, across the west branch of the Croton River. This dam, completed in 1873, is 670 feet long and 57 feet high, and created an additional storage of 2,700,000,000 gallons of water. The relief afforded by these works, however, proved merely temporary. The years 1876 and 1877 were so dry that the city was threatened with water famines, with the result that it was decided again to increase the supply and the quantity of water stored up.

The scheme drawn up—completed in 1884—gave an additional daily supply of 15,000,000 gallons. Its leading features were—(1) a dam converting the two Rye Ponds into a lake, with a storage capacity of 1,336,000,000 gallons; (2) a dam across the Bronx River at Kensico, forming a reservoir with a capacity of 1,627,000,000 gallons; (3) a dam across the Byram River, creating a lake of 180,000,000 gallons; (4) a channel, 3,800 feet long, uniting these two sources of supply; and (5) a pipe line from the Kensico Reservoir to Williamsbridge, the site of a receiving and settling basin.

Still a Shortage.

Large and sufficient as it appeared to be when first mooted, this enterprise had scarcely been commenced when it was demonstrated to be absolutely inadequate to the city's needs. In 1881, Mr. Newton, then chief engineer, presented a report to the Croton Aqueduct Commission, to the effect that the maximum safe discharge available from the aqueduct—namely, 95,000,000 gallons per day—had been supplied for several years; that to meet the prospective wants of ever-growing New York recourse must be had to a much larger watershed; and that there should be built an entirely new aqueduct capable of bringing to the city at least 200,000,000 gallons a day, even in the driest years.

So convincing were these representations that the State Legislature in 1883 accepted the plans prepared by Mr. Newton, and entrusted the construction of the new waterworks to a Board of Aqueduct Commissioners, consisting of the mayor and controller of the city, *ex officio*, and four members nominated by the former.

The New Croton Project.

The new scheme included the construction of a masonry dam across the Croton River, near Quaker Bridge, to form a reservoir with a surface of 3,635 acres and a storage capacity of 32,000,000,000 gallons. The reservoir was to impound water collected over an area of 361 square miles, and ensure a minimum daily supply of 250,000,000 gallons. Leading from

ANOTHER VIEW OF THE SPILLWAY, NEW CROTON DAM, SHOWING THE CHANNEL WHICH LEADS OFF THE SURPLUS WATER.

it there was to be an aqueduct, 12 feet in diameter, passing under the Harlem River and Manhattan Valley. This aqueduct, begun in January 1885 and completed in July 1890, consists of three parts: a masonry conduit, nearly 24 miles long, from Croton Lake to a great receiving reservoir of 1,900,000,000 gallons at Jerome Park; a masonry conduit under pressure thence for a further distance of nearly 7 miles to a gatehouse near Amsterdam Avenue; and a pipe line from this point to the receiving reservoir in what is now the heart of the city at Central Park. (See map on page 98.)

Of the masonry sections of the conduit, 29½ miles are constructed in tunnel. For blasting, exclusive of the quantity used in sinking the shafts, over 5,800,000 lbs. of dynamite were employed; and for lining the tunnel some 163,000,000 bricks were required.

At the public hearings held by the Aqueduct Commissioners in 1883 and 1884 for the discussion of the proposed plans, considerable opposition was manifested to the construction of the Quaker Bridge Dam, which was to be 100 feet higher than the highest masonry dam then existing. Consequently, it was not until 1892 that the contract for this part of the scheme was awarded. In the meanwhile, however, to satisfy the popular demand for "more water at once—or sooner," the Commissioners and Department of Public Works proceeded with the construction of a number

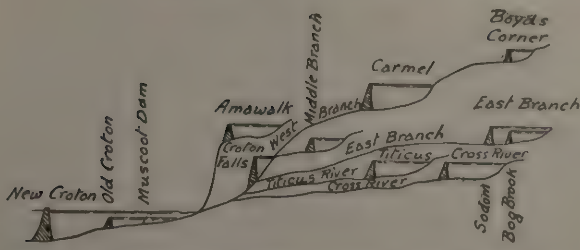


DIAGRAM SHOWING RESERVOIRS SUPPLYING THE NEW CROTON AQUEDUCT.

of storage reservoirs on branches and affluents of the Croton River.

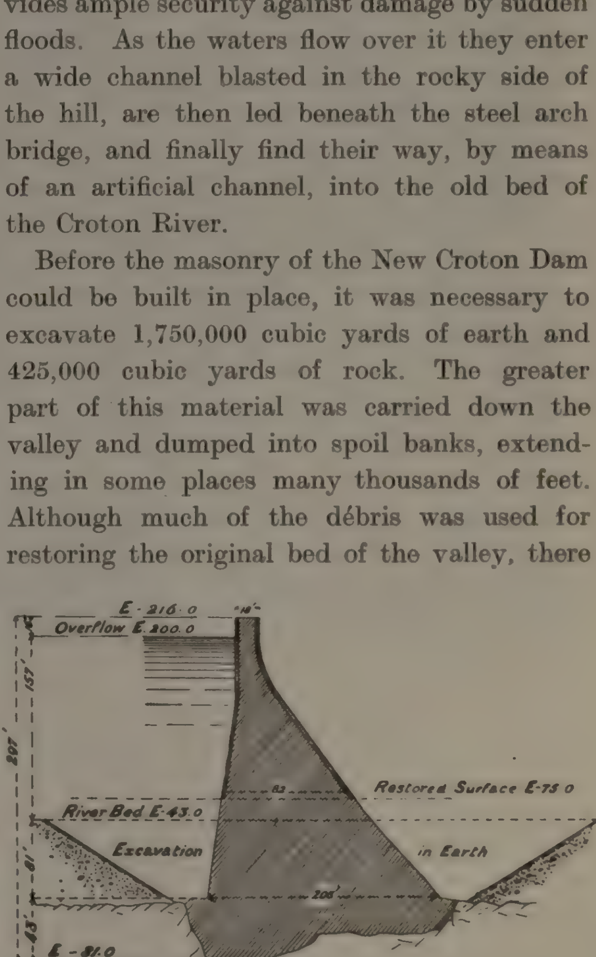
Early in 1891 the Aqueduct Commissioners resolved to construct across the Croton River, about 1¼ miles above Quaker Bridge, the already much-discussed high dam. As originally designed, this was to consist of a central masonry structure, 600 feet long; an earthen dam, with masonry core-wall of the same length; and a masonry overflow-weir, 1,000 feet long. In 1896, however, it was decided to extend the central portion 110 feet to the south, and correspondingly reduce the length of the earthen dam. The work was well in hand, and its early completion seemed assured, when, in 1901, Mr. W. R. Hill, the newly-appointed chief engineer, observed in the core-wall some small but, to his mind, ominous cracks. His prompt action following this discovery in all probability saved New York from a great catastrophe; for when the suspected portion of the dam was removed, prior to the substitution of masonry, the foundation was found absolutely unreliable. The changes in the plans now deemed necessary caused such delay in the construction of the dam that it was not until the middle of 1907—nearly fifteen years after ground was first broken—that the work could be pronounced complete.

The New Croton Dam.

From the photographs reproduced in this article one may gather a general idea of the architecture and imposing appearance of the finished structure. No pictorial representation, however, can convey an adequate impression of the dam's mammoth proportions. No one, for instance, unacquainted with the actual dimensions, would imagine that the height from the ground-level to the crest of the dam is 160 feet. The portion of the dam, moreover, seen above-ground constitutes but one-third of the actual mass of masonry in the structure. This extends 137 feet below ground in the centre of the valley, where the thickness of the dam upon the foundations exceeds 200 feet, thence narrowing symmetrically to 18 feet at the crest. The length of the dam from the southern abutment to the bridge is 1,168 feet, and that of the spillway from the bridge to its terminus up the valley 1,000 feet, making a total length of masonry of 2,168 feet. The spillway provides ample security against damage by sudden floods. As the waters flow over it they enter a wide channel blasted in the rocky side of the hill, are then led beneath the steel arch bridge, and finally find their way, by means of an artificial channel, into the old bed of the Croton River.

Its Huge Dimensions.

Before the masonry of the New Croton Dam could be built in place, it was necessary to excavate 1,750,000 cubic yards of earth and 425,000 cubic yards of rock. The greater part of this material was carried down the valley and dumped into spoil banks, extending in some places many thousands of feet. Although much of the débris was used for restoring the original bed of the valley, there



SECTION OF THE NEW CROTON DAM.

yet remained, when the dam was completed, many unsightly heaps, since utilized to advantage in the formation of an ornamental park on the downstream side of the structure.

The Cross River Dam.

The next great enterprise of the Aqueduct Commissioners to be completed was the Cross River Dam and Reservoir. The contract, awarded in June 1905, provided that the work should be completed in twenty-six months, and this condition—allowing for time lost owing to an injunction obtained against the Commissioners—was effectively complied with. Special features of this undertaking were the installation by the contractors of a combined system of multiple cableways and derricks, the provision of an equipment more extensive than is usual in the case of larger works, and the use of moulded concrete blocks instead of cut stone in the face of the dam. The main part of the latter, built of cyclopean masonry, is about 840 feet long and 175 feet in extreme height, with a width of 23 feet under the coping and 115 feet at the base. At the southern end the dam terminates with an abutment, from which a masonry core-wall is built for about 100 feet into the hillside. A circular structure, called a bastion, and a waste weir, 240 feet long, are built at the other end. The foundations of the dam are carried down to solid rock about 40 feet below the original low-water level of the river. The construction of another large storage reservoir at Croton Falls was begun in 1906, and is expected to be completed early in 1910. The magnitude of the works undertaken with a view to the increase and improvement of the supply from the Croton watershed may be estimated from the fact that the expenditures of the Croton Aqueduct Commissioners alone, during the twelve years ended in 1906, amounted to close upon £6,000,000.

CROSS RIVER DAM, SHOWING CONSTRUCTION.

CROSS RIVER DAM: CIRCULAR BASTION AND ABUTMENT AT THE NORTH END.

The present daily consumption of water by Greater New York is about 530,000,000 gallons, or more than twice the quantity with which 7,000,000 Londoners have to content themselves. Of the aggregate supply, 330,000,000 gallons are derived from the Croton watershed. This latter amount is 30,000,000 gallons a day more than can prudently be looked for in years of extreme drought, and only 50,000,000 gallons a day less than the maximum combined capacity of the "Old" and "New" Aqueducts. As the increase of water drawn through these conduits for several years has averaged 15,000,000 gallons a day each year, New Yorkers, ever prone to panic on the subject of water scarcity, readily scented danger from afar, and demanded, cost what it might, a new source of supply.

This movement, started long before the completion of the New Croton Dam, culminated a few years ago in the appointment of a commission of inquiry, the enactment of necessary laws, and the creation of a new authority. The Board of Water Supply of the City of New York, as the latter is called, has jurisdiction quite distinct from the municipal department controlling the Croton system. It decided to seek amid the Catskill Mountains, already world-famous for magnificent scenery, a suitable gathering-ground for the required waters; and eventually elaborated plans for a vast system of water collection, storage, and distribution, which, when completed, cannot fail to rank high among the most remarkable achievements of modern engineering.

A further Supply called for.

Preliminary investigations showed that the main dam, the controlling feature of the scheme, must be placed at one of two possible

CROSS RIVER DAM, AS SEEN FROM ABOVE. SPILLWAY ON RIGHT.

points. So exhaustive, however, was the inquiry into all the circumstances associated with the question, that it was not until early in 1907 that the Olive Bridge site was adopted. So valuable proved the mass of information collected for the official estimate that many would-be contractors made their bids upon it with only the briefest inspection of the site.

In all, five bids were received. The contract was awarded on August 31, 1907, to a firm with great experience in similar work, including the great Wachusett Reservoir at Clinton, Mass., and the Cross River Dam at Kotonah. Formal notice, however, to commence operations was not given until the following February. This delay was occasioned by an inquiry into the circumstances of the award, following a bitter campaign against the Board of Water Supply and its engineers for not accepting the lowest tender, and thereby, as was alleged, causing an extravagant waste of public money. This incident —watched with great interest by engineers and all concerned with municipal work on a large scale—would have made impossible the commencement of effective operations during the season of 1908 had not the contractors, of their own initiative, carried on preliminary work throughout the winter. As it was, the formal notice found them all but ready to instal machinery and begin excavation.

As shown on the accompanying plan below, the great Ashokan Reservoir will be formed by masonry and earth dams across Esopus and Beaver Kill Creeks, and by dikes closing up low parts of the valley on the east.

The Ashokan Reservoir.

It will have a length of about 12 miles, an average width of about 1 mile, and a shore line of close upon 40 miles. The maximum depth of water will be 190 feet, and the average depth about 50 feet, the flow line being at an elevation of 590 feet above sea-level. The total available capacity of the reservoir will be about 127,000,000,000 gallons, ample to cover the whole of Manhattan Island to a depth of 28 feet, and furnish Greater New

MAP OF ASHOKAN RESERVOIR.

The area which will be covered by water is dotted. The reservoir will contain 127,000,000,000 gallons, and furnish 500,000,000 gallons a day to Greater New York.

York with a daily supply of 500,000,000 gallons. The engineers, however, mindful of the dim and distant future when the city may demand a second aqueduct, have decided that the gate chamber, where the water supply from the reservoir will be controlled, shall have a capacity for handling daily no less than 1,200,000,000 gallons!

The Ashokan Reservoir is divided naturally into two basins, one in the valley of the Esopus, and the other in that of the Beaver Kill; and this separation will be completed by the construction of a weir and dike, each 1,100 feet long. Over the weir, which will be built of masonry, will pass, under certain conditions, flood water from the west to the east basin *en route* to the waste weir. This latter will be a masonry structure 1,000 feet long. The Beaver Kill dikes, in the aggregate 2·3 miles long, will rise about 110 feet above the original surface, and have a maximum width at the bottom of 650 feet. They will be built with concrete core-walls, and, with the dividing dike, will require in construction about 180,000 cubic yards of masonry and 5,000,000 cubic yards of other material.

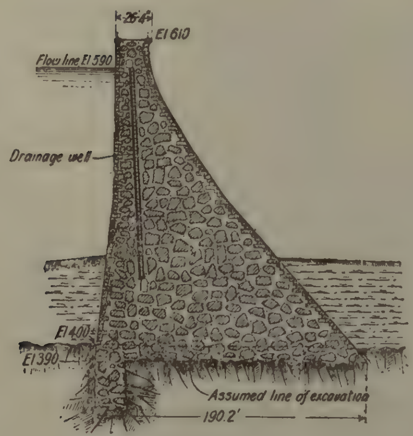
SITE OF OLIVE BRIDGE DAM.

The two huge 8 feet diameter steel pipes will carry off the water of the Esopus Creek during the construction of the Dam over them.

(Photo, by courtesy of the "Scientific American."

Little less impressive than the New Croton Dam will be that built across Esopus Creek. Its central mass, of concrete masonry, will be 1,000 feet long, 200 feet wide at the base, and have an extreme height of 240 feet from crest to bottom of the cut-off wall. Each end of the masonry will be flanked by an earthen wing about 1,800 feet long, with a maximum width at the base of 800 feet, and a top width of 34 feet. Core-walls of concrete, founded on rock, will be built into each of these wings. For the central portion of the structure there will be required about 550,000 cubic yards of masonry, and for the wings about 2,000,000

The Olive Bridge Dam.



SECTION OF OLIVE BRIDGE DAM.

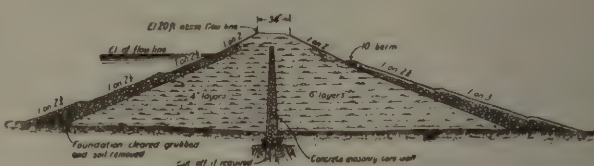
cubic yards of embankment materials. On the crest of the dam, which will be 610 feet above sea-level and 20 feet higher than the flow line in the west basin of the reservoir, will be built a roadway, 26 feet wide.

The amount of the contract for the construction of the Ashokan Reservoir, including nearly four miles of main dams and accessory works, is about £2,570,000. The date set for the completion of the contract is February 19, 1915, with a provision, however, that the work must be sufficiently advanced by August 1912 to permit of the storing of water in the west, or Esopus, basin, and its delivery into the aqueduct. The following are approximate estimates of the excavation and material required :—

Earth excavation	2,055,000	cubic yards.
Rock	425,000	„
Embankment and refilling.	7,200,000	„
Masonry.	874,000	„
Rubble paving and riprap	105,000	„
Portland cement	1,100,000	barrels.

The masonry structures for the most part will be "cyclopean"—that is, to quote the language of the specifications, "concrete, into which stones of various sizes, up to the largest that can be conveniently handled," will be embedded. The main dam will be faced with concrete blocks, and the same kind of material will be used as a lining for the inspection wells and at the expansion joints—two novel and interesting features in dam construction. All masonry dams, however well built, are liable to seepage, which, entering from the up-stream side, passes through the masonry, and issues from the down-stream face, producing a discoloration not only unsightly, but liable to create an impression that the structure is not tight. To prevent this, in the case of the Ashokan Dam, vertical drainage wells will be built into the masonry, terminating at top and bottom in inspection galleries. The position of these will be observed in the cross-section of the dam printed on the opposite side of the page.

Features of the Dam.



TYPICAL SECTION OF DIKES, ASHOKAN RESERVOIR.

The expansion and contraction joints are designed to localize the effect of changes of temperature. When cement is setting, the

VIEW ALONG LINE OF OLIVE BRIDGE DAM, SHOWING TRENCH FOR FOUNDATIONS.

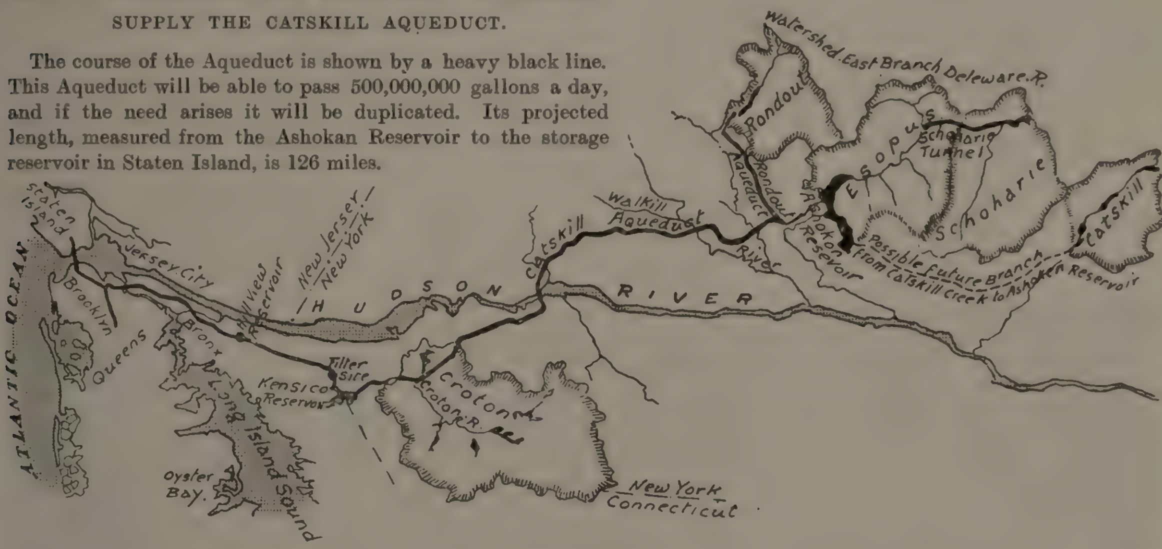
temperature of a large mass of masonry, such as a great dam, will rise as high as 120°, and then gradually fall to, say, 50°, these changes being, of course, accompanied with corresponding expansion or contraction of the structure. If the latter is built absolutely monolithic, as is usually the case, the expansion will produce cracks at one or more points, and these will not necessarily follow the joints in the masonry, but may result in the great stones being torn asunder during the shrinkage. By the provision, however, of vertical joints at intervals of every 84 feet of the length of the Ashokan Dam, the masonry will be divided into sections, and the total movement due to changes of temperature so distributed among a large number of joints as to become inappreciable at each. At the same time, it should be noted, the strength of the masonry to withstand the horizontal thrust of the water will be in no way impaired.

It being necessary to excavate at the site of the dam down to solid rock, provision has had to be made for passing away the waters of Esopus Creek. For the present, as shown in the illustration on page 105, this is being done by means of two 8 feet steel pipes. Later on, however, when the excavation is carried lower, a channel will be constructed for the same purpose along the side of the valley. Ultimately the water will be allowed to flow through a tunnel formed in the masonry of the dam, which will be closed when the dam is completed.

The future reservoir basin is at present crossed by a railway, for which a new location will have to be provided. Seven small villages also exist in the territory to be submerged. In all, to secure absolute control over the shores of the reservoir, 23 square miles of land will have to be acquired. There will also require to be built about 40 miles of new highway. For the accommodation of their employees, the contractors have built in the neighbourhood of the works about one hundred and sixty buildings, including a school, hospital, and engineers', doctors', and teachers' dwellings. Very elaborate provisions are included in the contract in respect of sanitation, inspection, and the like.

MAP OF WATERSHED AREA WHICH WILL ULTIMATELY SUPPLY THE CATSKILL AQUEDUCT.

The course of the Aqueduct is shown by a heavy black line. This Aqueduct will be able to pass 500,000,000 gallons a day, and if the need arises it will be duplicated. Its projected length, measured from the Ashokan Reservoir to the storage reservoir in Staten Island, is 126 miles.



The Catskill Aqueduct.

To deliver to the city the daily supply of 250,000,000 gallons, which the first development of the Catskill watershed is expected to yield, the construction of a great aqueduct —far surpassing any work of like character—

has already been commenced. In the first instance, in order to appease the bugaboo of water famine which periodically torments New Yorkers, this is to be connected with the New Croton system. Later on, however, the yields of the two groups of watersheds will be carried southward by, to all intents and purposes, quite independent means.

After passing beneath the New Croton Reservoir, the Catskill Aqueduct will be continued to Kensico, where another great reservoir is to be constructed, capable of storing 40,000,000,000 gallons, of which about half will be always available. This basin will be formed by a masonry dam, 1,200 feet long and having a maximum height of 250 feet, built across the valley of the Bronx. The dam will contain about 1,000,000 cubic yards of masonry, and be 28 feet wide at the crest and 230 feet wide at the bottom.

Four miles south, at Scarsdale, a large filtering plant is projected, and thence the aqueduct will be continued for a further distance of six miles to Hill View, just outside the city boundary. Here is being built a distribution reservoir, with a capacity of about 800,000,000 gallons—an ample insurance, it would appear, against possible difficulties caused by any sudden interruption of supply by failure of the ninety-two miles of aqueduct to the north. By the construction below the East River of a huge tunnel of 200,000,000 gallons daily capacity, of a storage and distribution reservoir in Brooklyn, and of a great pipe line carried

CUT-AND-COVER SECTION OF THE CATSKILL AQUEDUCT, SHOWING CONCRETING OVER STEEL MOULDS.

Observe the reinforcing steel bars.

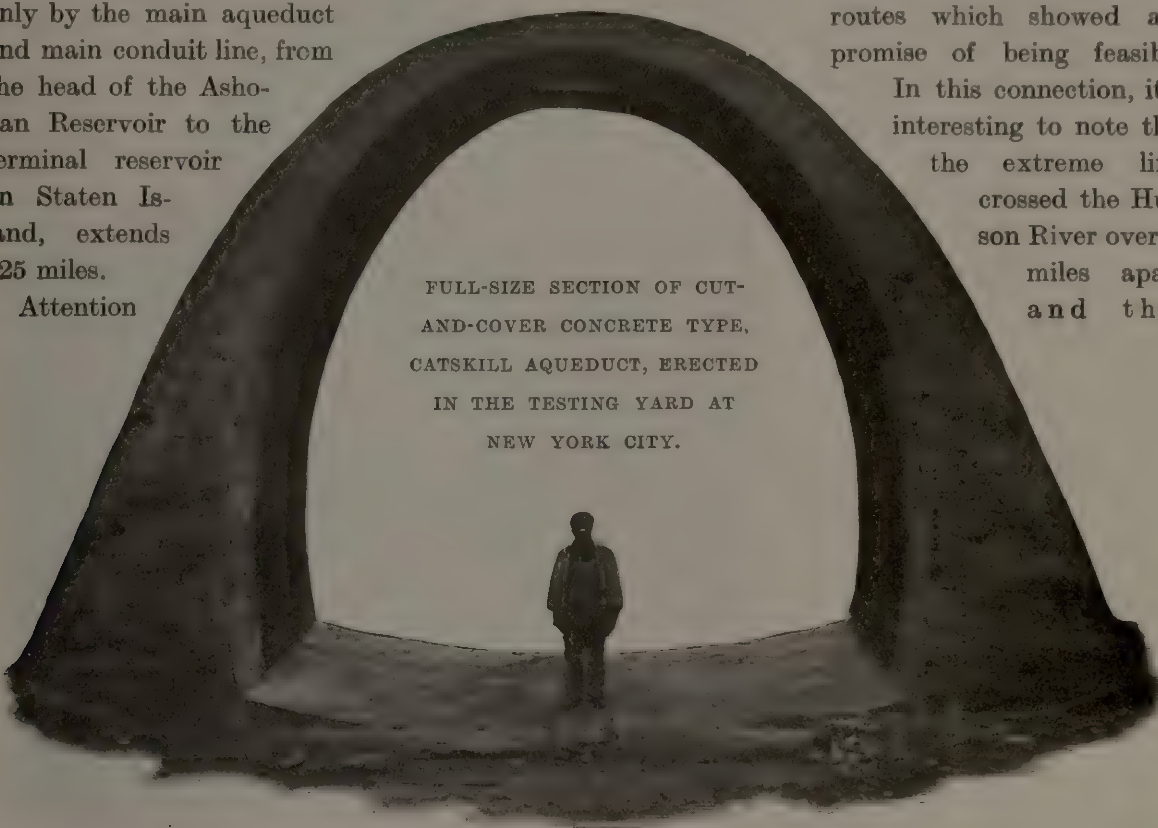
through that city and below the Narrows to Staten Island, the water wants of these portions of Greater New York should be fully provided for.

Altogether, the territory covered by the new water supply, measured only by the main aqueduct and main conduit line, from the head of the Ashokan Reservoir to the terminal reservoir on Staten Island, extends 125 miles.

Attention must here be called to the extraordinary dimensions and characteristics of the new aqueduct as an engineering structure.

A Colossal Enterprise.

Wherever possible, the conduit is being built of concrete and in open cut, with a horseshoe section of 17 feet high by 17½ feet wide—or 3½ feet higher and 4 feet wider than the normal section of the New Croton Aqueduct tunnel. The tunnels on the hydraulic gradient will also have a height of 17 feet, but, consequent on the greater slope allowed, the width is reduced to 14 feet 4 inches. Elsewhere, valleys and rivers have to be crossed by pressure tunnels below grade, cut deep in the rock, and having a circular waterway about 14½ feet in diameter.



FULL-SIZE SECTION OF CUT-AND-COVER CONCRETE TYPE, CATSKILL AQUEDUCT, ERECTED IN THE TESTING YARD AT NEW YORK CITY.

Before the line was definitely laid down, a careful study was necessary, first on the maps of the United States Geological Survey, and then in the field, of all routes which showed any promise of being feasible. In this connection, it is interesting to note that the extreme lines crossed the Hudson River over 20 miles apart, and that 57,000 acres were covered by the topographical surveys. The ideal route, of course, would have been a straight one, along which the aqueduct could be constructed in open cut on the hydraulic gradient. As this was out of the question, the engineers directed their attention to securing, without undue increase in the length of the line, the smallest percentage of tunnel and siphon. How far they succeeded will be seen in the following table :—

Distance between Ashokan Reservoir and Croton Lake	54	miles.	
Aqueduct at grade in cut-and-cover	36·35	„	60%
Aqueduct at grade in tunnel	6·66	„	11%
Aqueduct below grade in siphon	17·25	„	29%
Total	60·26	miles.	

Exploratory Work.

On account of the enormous hydrostatic pressure to which it is subjected, a siphon tunnel must be deep in perfectly sound rock. Consequently, wherever this type of construction was found necessary, very extensive explorations had to be made by means of wash or core borings before the route of the aqueduct could be definitely determined. The magnitude of this preliminary work will be evident when it is remembered that along the line of the Ashokan Aqueduct the surface—or, as the geologists call it, glacial material—usually covers the rock to a depth of several hundred feet.

STEEL MOULD FOR CUT-AND-COVER WORK, CATSKILL AQUEDUCT.

(Photo, by courtesy of the "Scientific American.")

And here let it be noted, for the benefit of the uninitiated, that drilling in earth, especially at a great depth, is usually more difficult than boring through the hardest of rock. If the rock is of uniform quality, a progress of 10 to 30 feet a day can often be maintained; whereas the presence of a gravel bed or boulder in the surface material may bring on troubles sufficient to cause a delay of weeks in boring a few feet. Where the rocks are very hard, the diamonds and other cutting agents wear away rapidly; but, speaking generally, this trouble is of small account compared with that caused by the occurrence of a soft spot, resulting in the caving in of the walls of the hole.

Up to the present the total length of wash and core borings in connection with the Ashokan Aqueduct exceeds 25 miles! The borings have ranged in depth from a few feet to nearly 700 feet in the Rondout Valley and over 1,000 feet in the gorge of the Hudson River, where, for reasons which will be explained later, the exploration difficulties have been exceptionally great. West of the river, in addition to three streams, three wide valleys will require siphons, each from $3\frac{1}{2}$ to $4\frac{1}{2}$ miles long. On the other side, also, several tributaries of the Hudson must be crossed by similar means. The following are all the siphons in this section of the aqueduct—from Ashokan Reservoir to Croton Lake—arranged in geographical order from north to south, with the type of construction and approximate length of each :—

Esopus, steel pipe	1,850 feet.
Tangore, steel pipe	700 ,,
Rondout, rock tunnel	23,610 ,,
Wallkill, rock tunnel	23,400 ,,
Washington Square, steel pipe	3,550 ,,
Moodna, rock tunnel	19,800 ,,
Hudson River, rock tunnel	4,450 ,,
Foundry Brook, steel pipe	3,800 ,,
Indian Brook, steel pipe	600 ,,
Sprout Brook, steel pipe	2,270 ,,
Peekskill Creek, steel pipe	7,040 ,,
Total	91,070 feet.

The Hudson River Crossing.

The crossing of the Hudson River was regarded from the very first as one of the most difficult features of the Catskill development scheme, and that this will actually prove to be the case is now certain. It was originally proposed to cross the river at New Hamburg; but the preliminary borings here, as at other suggested sites, failed to expose rock sufficiently free from fissures and other imperfections to justify confidence that it would be able to withstand the enormous pressure of water at the depth below the river bed to which the tunnel would have to be sunk. The attention of the engineers was consequently directed to the country between Cornwall and West Point, where geologists assured them a thoroughly sound and reliable granite would be found. For various reasons, a line crossing the river from Storm King Mountain on the west to Breakneck Mountain on the east was selected. Here the hills rise precipitously to more than 1,200 feet above the water, and the river is 2,800 feet wide and 90 feet deep.

A Serious Obstacle.

At this picturesque spot costly and laborious operations—necessarily suspended during the severe winter months—have been in progress since September 1905, but so far with invariably disappointing and perplexing results. The putting down of vertical holes in the bed of the river having proved unavailing, and a difficult undertaking on account of the interference by navigation and the violent winds which frequently blow through the gap, wash and core borings have in turn been abandoned. A deep test shaft has now been sunk on each shore of the river, and from these shafts horizontal drill borings are being made under the river bed. Up to January last, the deepest boring under the river had been sunk 626 feet below tide-level, or nearly 1,030 feet below the aqueduct on the western slope of the river, but without encountering rock. It is consequently evident that the huge inverted siphon by which it is proposed to convey the Catskill water across the Hudson must be carried to a much greater depth than was originally anticipated, and that its construction will involve much unexpected difficulty and cost.

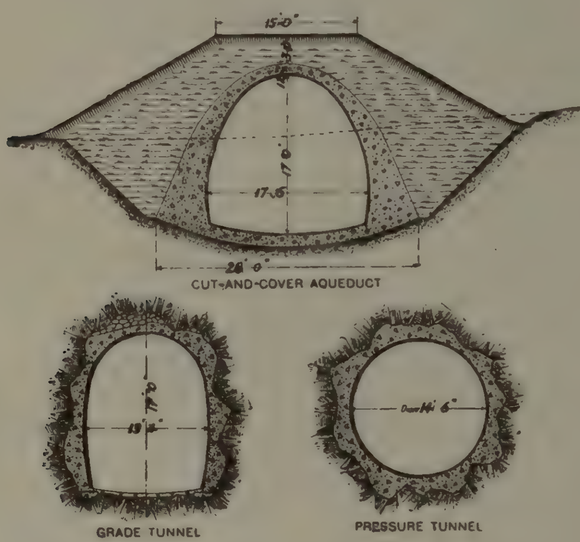
As was truly remarked by one of the orators on the occasion of the inauguration of the work, "This mighty aqueduct will take from no man anything that is needful to him. It will bring the purest and most healthful of all drinks to myriads of citizens of New York both in the present and the future. It will carry to their homes the means of cleanliness and happiness. It will be a safeguard to the household gods of the poor and to the merchandise of the captains of industry."

Still Looking Forward.

Reference to the map printed on page 107 will show that the policy of "looking forward" looms large among the responsible authorities, and that—so far at least as plans are concerned—little is to be left to chance in the future. If more water should be demanded when the present enterprise is completed—at an estimated cost, for the first installation of 250,000,000 gallons daily, of £23,093,000, and for double that quantity of £33,402,000—inroads will be made on the yields of adjacent watersheds. The first threatened is the Rondout, which is said to be capable of yielding 130,000,000 gallons daily. In this it is proposed to construct two reservoirs—Lackawack and Napanoch—with capacities of 13,270,000,000 and 4,760,000,000 gallons re-

spectively, from which the waters would be led by an aqueduct into the main Catskill Aqueduct about two miles below the Ashokan Reservoir. Later, the Schoharie watershed will be brought into service by the construction of the Prattsville Reservoir, with a capacity of 9,400,000,000 gallons, brought into Esopus Creek by means of a 10 miles tunnel through the mountains. Finally, the Catskill waters will be impounded in three reservoirs—at Franklinton, Preston Hollow, and Oak Hill—with an aggregate capacity of nearly 25,000,000,000 gallons, and brought into the Ashokan Reservoir by an aqueduct running south between the mountains and Hudson River. These extensions of an already colossal undertaking would put at the command of Greater New York an additional daily supply of 200,000,000 gallons of water.

For much valuable information, helpful to the production of this article, the author desires to express cordial acknowledgments to Mr. Walter H. Sears, chief engineer of the City of New York Aqueduct Commission; and to Mr. J. Waldo Smith, chief engineer, and Mr. Alfred D. Flinn, department engineer, of the Board of Water Supply.



CATSKILL AQUEDUCT: TYPICAL SECTIONS.

BUILDING TRESTLES ACROSS THE BREACH.

THE COLORADO RIVER CLOSURE.

The Story of a Three Years' Struggle to close a Breach in the Banks of a Great River.

AMONG the many tasks that fall to the lot of the engineer is that of altering the flow of a river. Perhaps a stream bursts its banks and changes its course: it must be forced back into its original bed. Or, on the other hand, it may be necessary to divert a river from its natural path for irrigation or other purposes.

Such undertakings are usually effected without difficulty, by throwing dams across a breach in a broken bank, or by digging a new channel, as circumstances may need. But in the case of the Colorado River outbreak and closure the problem was such as to make its solution a matter of world-wide interest.

The Colorado River.

The Colorado is one of the largest rivers in the United States. It rises in the Rocky Mountains of Utah, and after flowing through the Grand Canyon and traversing a stretch of flat country, empties itself into the Gulf of California. The flat stretch referred to commences at Yuma. Some hundreds of miles west of this town is a dried-up ocean bed known as the Salton Sink. It lies about 300 feet below sea-level, and was, until recently, useless to man, except for the great salt deposits found in its deepest depressions. Presently some one discovered that the soil of the basin—detritus deposited by the river during the course of ages—had a natural marvellous fertility when brought into contact with water. In 1896 a scheme was inaugurated, under the name of the California Development Company, to divert part of the waters of the Colorado into the Imperial Valley, an upper bench of the Sink. Nature had prepared the way by cutting a channel, filled only at exceptionally high floods, many miles through the valley, from a point about twelve miles below Yuma. It was necessary only to turn water into this canal to lead it practically fifty miles in the requisite direction.

An Irrigation Canal made.

In 1900 the Development Company tapped the river several miles above the point at which this dry channel left the Colorado, put in a headgate or sluice some 80 feet long, and dug an artificial canal parallel to the river from this headgate to the channel. (See Fig. 1.) This last was made the feeder of many smaller irrigating canals and ditches

SUNSET ON THE SALTON SEA, FORMED BY THE WATERS OF THE COLORADO RIVER.

In August 1906, when this view was taken, the sea had a length of over forty miles.

intersecting the Imperial Valley in all directions. The valley proved to be marvellously fertile, its soil producing a crop of alfalfa grass in six weeks. Settlers were attracted, and soon 12,000 persons were cultivating 2,000 farms in a region hitherto practically uninhabited by man.

The waters were turned into the valley in

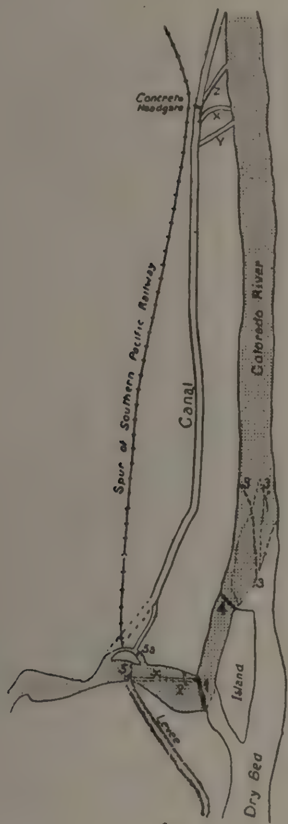


Fig. 1.—SKETCH MAP TO SHOW THE LOCATIONS OF THE FIRST FIVE ATTEMPTS MADE TO CLOSE THE BREACH IN THE RIVER BANK.

The course of the water during these operations is shown by the shading. The Figs. indicate:—1. First attempt, January 1905. 2. Second attempt, May 1905 to June 1905. 3. Third attempt, July and August 1905. 4. Fourth attempt, October 13 to November 29, 1905. 5. Fifth attempt, January 8 to October 11, 1906. The small canal, *x*, cut to increase the volume of irrigation water, was the cause of all the trouble.

June 1901. Unfortunately, in their haste to complete their contract up to time, the engineers placed the floor of the headgate five feet above the level originally planned, and too high to pass water at the river's lowest state. As a result the connecting canal silted up, and though dredgers were kept at work, the water delivered did not meet the needs of the many settlers. To remedy matters, a ditch (marked *x* in Fig. 1) was cut—late in 1904—from the channel to the Colorado direct, about four miles below the original headgate. This ditch, 50 feet wide, had a fall of 1½ feet in its 3,300 feet; but despite its ample dimensions it soon became obstructed. It was cleared, only to close again. A third time the engineers opened it, and then occurred a flood which widened and deepened the ditch until the Colorado chose an easier way down into the Sink, leaving its bed dry below the breach and its old estuary waterless.

A Serious Mishap

This unexpected mishap portended terrific consequences. Unless checked, the river would fill up the depression to sea-level, and create the largest body of water in the United States. To stave off ruin from the settlers, it was imperative to turn the river back into its old bed—a task far more difficult than was at first anticipated, as the story will show.

To understand the operations of the next two years, the reader should refer to the two sketch maps, Figs. 1 and 2, which show by numerals the localities of the seven attempts made to close the breach.

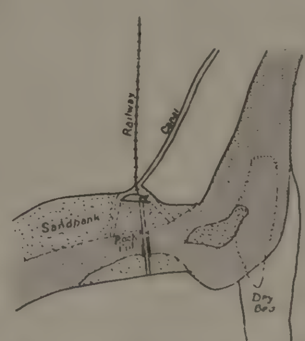


Fig. 2.—MAP SHOWING THE POSITION OF OPERATIONS DURING THE SIXTH AND SEVENTH ATTEMPTS TO CLOSE THE CREVASSE.

The first attempt, begun in January 1905, consisted of driving down piles 3 feet apart across the entrance to the crevasse cut by the stream, and filling in the spaces with brushwood and bags of sand. The supply of sacks failed before the work had been completed, and during the wait for more the half-finished dam gave way. This made the engi-

The First—

neers realize that more aggressive measures were needed for the conquest of the river, though further operations were postponed until the following May. Two rows of piles, 15 feet apart, were then carried out from the right bank of the channel; but the obstruction served only to

and Second Attempts to close the Breach.

Company, owing to exhaustion of funds, could no longer conduct. Colonel Randolph, Vice-President of the railway, resident at Tucson, an eminent engineer with a wide experience of river work, was put in command, with Mr. C. E. Rockwood, the engineer who had conceived the irrigation scheme, as chief executive.

STEAMBOAT AND CREW PREPARING TO DAM THE INTAKE: FIRST ATTEMPT.

make the river erode the other bank, so that the gap was not lessened. After a month's work the attempt had tc be abandoned.

By this time the Salton Sink had become a great lake, forty miles long. Destruction threatened the track of the Southern Pacific Railway, which skirted the northern edge of the lake and the railway management, urged by the law of self-preservation, had to take hold of the business which the Development

Their predecessors had not realized fully the strength of the Colorado. Fed by melting snow, the river naturally floods in the season —May to September—when the sun has greatest power. Like other rivers traversing arid regions with no vegetation to regulate the off-flow of the water, the Colorado has a maximum flow many times—about fifty—greater than the minimum. During a flood period the quantity of water passing a given

point is half that of the Niagara River at the famous falls. Furthermore, the Gila River, which enters the Colorado just above Yuma, is subject to heavy spates caused by cloudbursts, and in a few hours swells from a trickle into a raging torrent discharging almost as much water as the main stream itself. Another feature of importance is the character of the Colorado's bed—deep silt unfathomable by borings and piles, and so fine that flowing water disintegrates it with the greatest ease.

Having acquainted themselves with the peculiarities of the river, the engineers made a third attempt to stop the breach. They drove piles obliquely across the stream to the upper end of an island—fitly called Disaster Island, as it was subsequently washed away—hoping thus to turn the waters into the channel to the left of the island, and cause the formation of a sandbank at the entrance of the crevasse. But a sudden rise of the river undermined and removed the piles, and August 1905 saw this attempt abandoned.

The Third Attempt—

The engineers did not despair, however. A brush and pile dam (3 in Fig. 1) was stretched across the Mexican or right channel to the upper end of the now partly destroyed island. It had been almost completed when an exceptionally high flood of the Gila swept down on and destroyed the works. So ended effort number four.

and the Fourth.

Two days before the disaster a contract had been signed for the construction of a steel reinforced concrete headgate near the intake at the upper end of the canal, about 1,500 feet from the river bank. The gate was designed to pass 10,000 cubic feet of water per second, and enable all the river to be diverted through it at low water into the old canal and allow the breach opposite the island to be dammed. The canal itself also required widening; and as this work could not be effected quickly, it was decided to construct simultaneously a wooden headgate (5*a* in Fig. 1) beside the breach, and afterwards dam the breach opposite this headgate. Owing to unavoidable delay the wooden gate was not completed soon enough to permit opening the by-pass leading to it, and building the dam, before the occurrence of the ensuing summer floods (1906), which were particularly severe, and extended the width of the crevasse from 600 to about 2,600 feet, depositing a sandbank 1,500 feet long in front of the headgate (see Fig. 2). This complicated matters seriously. The engineers determined to erect a dam 3,000

The Concrete Headgate.

WATER EATING ITS WAY THROUGH THE RIVER BANKS.

SIXTH ATTEMPT: FORMING A DAM BY DUMPING MASSES OF ROCK.

THE WATERS WASHING AWAY A HOUSE.

The side of the house is seen in the act of falling.

The scene now became one of great activity. Hundreds of teams, two dredgers, and several steam - shovels got to work. Six hundred feet of the opening were mattressed; brush fascines, eighteen inches in diameter, held together by strong foundation cables, were dumped against piles driven at intervals. The current found a way under the mattress and below the masses of piles and brushwood which reinforced the ends of the mattress.

Strenuous Work.

feet long across the breach, and construct 5 miles of levees (artificial banks) 5 miles down-stream, and 3½ miles up-stream from the wooden to the concrete headgate; also to deepen the old canal, and make a new cut (Z) from the river to the upper headgate. About 300,000 cubic yards of material were to go into the dam and 400,000 yards into the levees. For so colossal a task great preparations were necessary. The intense heat of the climate made it difficult to obtain sufficient labour until Indians had been recruited from far and near and accommodated in a comfortable camp at the dam site. To handle materials and supplies a spur track was built from the Southern Pacific main line at a point 10 miles west of Yuma. This spur was 11 miles long, including sidings. Quarries were opened, clay and gravel pits developed, and preparations made for weaving huge mattresses to aid in the closure. In the course of a few months 1,100 piles, 2,000 bundles of willows, 40 miles of steel cable, and 70,000 tons of rock had been collected for incorporation into the dam. Meanwhile the engineers shifted 40 miles of the Southern Pacific track to escape the waters of the encroaching Salton Sink. Four times were the rails moved for this reason during the closure operations.

The Fifth Attempt.

A trestle for railway tracks was accordingly constructed along the centre line of the proposed dam, and car loads of rock and gravel were dumped until the water was penned and diverted through the wooden headgate. However, the Colorado made another effort for freedom, rose, and brought down large quantities of driftwood which blocked the gate. This caused the undermining of the gate, and despite attempts to weight it down with rocks, the water suddenly tore away some 120 feet of the structure and swept it down-stream. The scouring created a channel—fitly called the New River—through the Imperial Valley. Fields of grain and vegetables, orchards and fruit gardens, entire farms, also hundreds of houses, were swept away by the invading torrent. This disaster closed chapter five.

Another Disaster.

The engineers took counsel together, and quickly evolved a fresh plan of campaign. This was to throw three parallel lines of trestles, each to carry a railway track, across the breach, and dump the largest stones obtainable across the by-pass breach, and turn the water through an opening made in the dam. The Southern Pacific Railway authorities made a

The Sixth Attempt.

SIXTH ATTEMPT: WATER PASSING THROUGH THE DAM TRESTLES.
CONSTRUCTION TRAIN ON THE DAM WHICH FINALLY CLOSED THE BREACH.

DUMPING EARTH AND STONES TO FORM THE DAM.

tremendous effort to carry out the scheme, utilizing every quarry within a radius of 400 miles, and dumping daily 200 car loads of the rock thus obtained. The work began on November 24, 1906. Twenty days later the breach was closed, and the water had been forced into the old bed of the Colorado—all, that is to say, which was not drawn off through the concrete headgate to supply the irrigation needs of the valley.

Just when the fighters were beginning to congratulate themselves on having at last subdued the river, it breached the levee below the dam, and soon had eaten out an opening two-thirds of a mile wide.

The Seventh Attempt.

The seventh and last struggle began on January 27, 1907. Three lines of trestles, resting on piles 65 to 90 feet long, were reared across the break, at the cost of several failures and great labour. It was actually necessary to weight the piles with water tanks placed on top to prevent them being loosened by the water. In all, some 100,000 cubic yards of rock and 75,000 yards of clay and gravel were deposited from the trestles. The dams gradually ponded up the river until, when it had attained a depth of 12 feet, it resought its old channel. The fight was definitely won by the end of February. The month's work had been most severe, calling for the services of nearly 1,300 labourers—including 375 Indians—600 horses, 7 locomotives, a steamboat, and a fleet of barges, dredgers, and pile drivers.

Success at Last.

The contest between man and river had lasted three years, and its termination reflects the highest credit on the organization of the Southern Pacific Railroad, which alone could have carried the business through in time to save the Imperial Valley, and also on the engineers in charge of operations—Colonel E. Randolph and Messrs. C. E. Rockwood, H. T. Cory, T. J. Hind, C. K. Clarke, and E. Carrillo.

As the dams and levees have withstood some severe floods, it seems unlikely that the river will "take charge" again. Even if such a catastrophe should happen, the engineers, taught by experience, should have less difficulty than before in forcing the waters back into their natural channel.

PART OF THE COLORADO RIVER LEVEES, OR CONTAINING BANKS, WHICH HAD A TOTAL LENGTH OF 8½ MILES, AND CONSUMED HALF A MILLION CUBIC YARDS OF MATERIAL.

SOME EXTRAORDINARY SHIPBUILDING FEATS.

Fig. 1.—S.S. "WITTEKIND" IN DRY DOCK AT THE YARDS OF MESSRS. SWAN, HUNTER, AND WIGHAM RICHARDSON, LIMITED, WALLSEND, FOR LENGTHENING 60 FEET. NEW FLOORS IN POSITION.

BY ALBERT G. HOOD,

Editor of "The Shipbuilder."

An account of ships and shipbuilding would be incomplete without some reference to what may be termed extraordinary shipbuilding feats. Occasionally the requirements which have to be fulfilled are so unusual that the naval architect finds it necessary to evolve an entirely new type of vessel, and of the ingenuity displayed under these circumstances a very interesting chapter might be written.

To meet, for example, the needs of navigators in waters which are frozen over in winter, many vessels have been specially designed for forcing their way through ice.

The Ice-Breaker "Ermack."

The most remarkable ice-breaker so far constructed is the *Ermack*, built by Messrs. Armstrong, Whitworth, and Company, to the designs of the late Admiral Makaroff, the brave Russian commander who perished at Port Arthur during the Russo-Japanese War. As originally constructed, she was 305 feet long, of 71 feet beam, and 42 feet 6 inches deep to the upper deck, with a displacement of 8,000 tons. Her engines indicate 8,000 horse-power, and give the vessel a speed in open water of 15 knots. Built of steel, she has very great strength, her bow particularly being strong enough to with-

stand impact with heavy ice. Her transverse form is such that when wedged between masses of ice she will tend rather to rise than be depressed. Her bow slopes upwards from below, so as to enable her to run up on the ice and thus use her weight to break it; while her stern is so shaped as to afford the maximum protection for the screw propellers against ice.

When she left her builders' hands the *Ermack*, in addition to three screws aft, had one fitted at the fore end, which was intended to disturb the water below the ice, and so assist the weight of the ship in breaking through. While working in thick field ice, however, the shaft of the forward screw became bent, and it was found necessary to remove the screw. Later, the vessel returned to the Tyne, and a new fore-body was built, omitting the forward screw. The ship was then docked, the old bow cut away, and the enlarged fore-part joined on, the length of the ship being increased to 320 feet. Fig. 2 is from a photograph taken while the ice-breaker was in dry dock for this alteration, and shows the new bow in position. The *Ermack* proved herself capable of crushing with comparative ease the ice met in the Baltic in the middle of winter, and on an experimental voyage to the Polar Sea north of Spitzbergen she made her way through vast ice-fields, and successfully encountered floes of the greatest thickness.

Transporting Submarines.

The increased use of submarines as adjuncts to the world's fighting fleets has confronted the naval architect with a good many problems apart from those involved in the design and construction of the craft themselves. It is well known that when a flotilla of submarines are engaged in manœuvring some distance from shore, they are usually accompanied by a "mother" ship; but the general public are not so familiar with the special means employed for transporting submarines when it becomes necessary to convey them from one part of the world to another. Recently Messrs. Vickers Sons and Maxim,

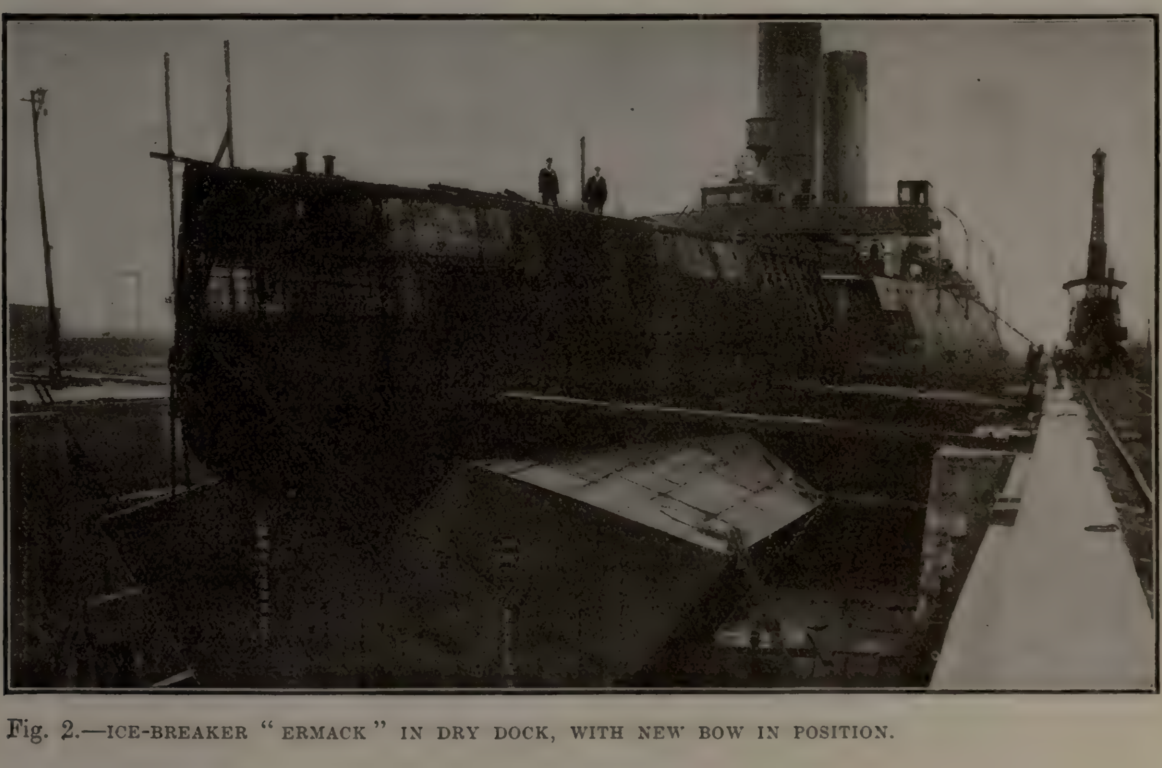


Fig. 2.—ICE-BREAKER "ERMACK" IN DRY DOCK, WITH NEW BOW IN POSITION.

who have made a speciality of the building of submarines, had occasion to send two of these vessels to Japan, and for this purpose they employed a specially constructed ship, named the *Transporter*. The submarines were each about 135 feet long and 250 tons weight. The *Transporter* was taken to a graving dock in the Mersey; the port rail, part of her deck, and all the cross beams were removed, and the vessel was submerged. The first submarine was then floated into the dock and over the *Transporter's* hold, and the water in the dock pumped out. As it dropped, the submarine was carefully bedded on chocks, previously fitted, by divers and secured. The operation was afterwards successfully repeated with the second submarine, when the deck, etc., of the transport ship was replaced, and she eventually sailed for Japan with her strange freight.

The frequency of accidents to submarines has led the German Government to construct a special vessel for raising sunken submarines, and also for lifting torpedo boats and submarines out of the water. This dock-ship, built to the designs of Naval Constructor Ph. von Klitzing, was an interesting item in the shipbuilding output of the Howaldtswerke of Kiel in 1908. The vessel, as will be seen on reference to Fig. 3,

A Dock-Ship for Submarines.

Fig. 3.—THE "VULKAN," A GERMAN DOCK-SHIP FOR TORPEDO BOATS AND SUBMARINES.
The vessel has practically two hulls, joined by an arch-like superstructure.

has practically two hulls, linked together at the upper part in a fore and aft direction. A small craft can thus be propelled into the archlike aperture between the two hulls, and by means of the hoisting gear supported from the lattice-work portals or bridges fitted to the upper part of the dock-ship it can be lifted clear of the water. When this operation is completed, beams are swung out from both of the inner sides of the dock-ship, thus forming a platform for the support of the small vessel. The *Vulkan*, as the dock-ship is called, is 269 feet long and 77 feet wide, this great width being necessary to allow the passage of small craft between the two hulls. Her lifting capacity is 1,400 tons, and two

vessels can be carried at the same time. In the event of a submarine being unable through any cause to regain the surface, or a torpedo boat sinking after collision or through sustaining damage in any other way, the *Vulkan* can proceed under her own power to the scene of the accident, raise the sunken craft, and bring it safely to port.

Fig. 4.—SALVED PORTION OF S.S. "MILWAUKEE" IN DRY DOCK.
Plates twisted by the blasting with dynamite required to cut her in half.
(*Photo, Messrs. Swan, Hunter, and Wigham Richardson.*)

Ship-Lengthening.

The feat of lengthening an existing ship has several times been carried out when, owing to the altered conditions of the trade in which she is employed or for some other reason, she has proved too small. One of the earliest cases of ship-lengthening—at least of which any accurate account has been put on record—was that of the P. and O. Company's steamship *Poonah*, which in 1874 was lengthened 80 feet under the superintendence of Mr. E. W. De Rusett, M.Inst.C.E. Other notable vessels similarly treated were the P. and O. liners *Rome* and *Carthage*, the Cape mail steamer *Scot*, the Carron Company's steamers *Forth* and *Thames*, and the Norddeutscher Lloyd's liner *Wittekind*. In 1900 the last-named vessel was cut in two in the dry dock of Messrs. Swan, Hunter, and Wigham Richardson, pulled apart for 60 feet, and a new portion built in, the ship being increased from 386 feet to 446 feet long. Fig. 1 illustrates the vessel in dock, the two portions apart, and the new floors in position. After this alteration the *Wittekind* was to all appearances a new and perfectly symmetrical ship, the work being regarded by experts as one of the most successful ship-lengthening feats ever undertaken.

The "Wittekind."

Ship-repairing Extraordinary.

Many instances might be cited to show the intricate work which shipbuilders and repairers at times are called upon to accomplish after a severe casualty at sea; but probably no more interesting and noteworthy cases of repair could be quoted than the

work at the large steamer *Milwaukee* and the White Star liner *Suevic*. In the autumn of 1898 the former vessel went ashore at Port Errol, near Peterhead, in bad weather.

The "Milwaukee."

It was soon recognized that the whole of the vessel could not be salved, but that, while a large portion of the fore end was inextricably jammed, the remainder, if detached therefrom, might perhaps be successfully floated. To effect the severance a belt of dynamite cartridges was exploded round the shell of the vessel, and after several such explosions a complete division was made forward of the machinery space without seriously injuring the adjacent parts of the structure. So strongly had the *Milwaukee* been constructed that no less than 3,350 lbs. of dynamite were exploded in cutting her asunder. The most interesting demonstration of her strength, however, was afforded by the subsequent behaviour of the transverse water-tight bulkhead at the forward end of the boiler space, upon the strength and tightness of which the vessel depended to keep her afloat until placed in dry dock for repairs. When cut in two the after part, extending from just before the forward end of the navigating bridge, was not only safely floated, but towed with the bulkhead end foremost (the tug-boats being assisted by the ship's own engines) to the Tyne, and moored there until a new bow-end had been built, launched, and made ready for connection to it. A facsimile of the fore part of the vessel left behind on the Scottish coast, 180 feet in length, was launched by the original builders of the vessel (Messrs. Swan, Hunter, and Wigham Richardson), and for several days afterwards the bow and stern portions of the *Milwaukee* floated side by side and pointed in the same direction (see Fig. 6), one of the very few instances, if not the only one, in which the bow

Fig. 5.—SALVED PORTION OF S.S. "MILWAUKEE" WITH DAMAGED PLATES REMOVED.

(*Photo, Messrs. Swan, Hunter, and Wigham Richardson.*)

and the stern of a vessel have been known to look the same way. Our illustrations tell the interesting story. Fig. 4 shows the salved portion of the vessel in dry dock, with dynamite-fractured ends; Fig. 5 shows the fractured and ragged ends removed; and Fig. 6 illustrates the old and new parts afloat before being joined together. So accurately was the whole of the work accomplished that the vessel's principal dimensions were exactly as they had been, and her gross tonnage differed by only six tons from what it had been originally. During the South African War the *Milwaukee* was chartered by the British Government as a transport, and it was in this vessel that the redoubtable Boer general Cronje was sent to St. Helena after his surrender to the British forces. Since that time the vessel has seen much service in the heavy North Atlantic trade, and she has never shown any signs of weakness.

The story of the more recent disaster which overtook the White Star liner *Suevic*, by running ashore at the Lizard, will be remembered by many of our readers. The recovered portion of the vessel—representing about two-thirds of her total length, and comprising the valuable propelling machinery—was safely towed round to Southampton, docked there, and generally prepared for junction with a new forward part, which was built and launched by Messrs. Harland and Wolff. The *modus operandi* of joining the two portions in dry

The "Suevic."

dock was generally similar to that followed in the case of the *Milwaukee*, and now the vessel is once more "walking the waters like a thing of life."

And thus we might continue to relate

Fig. 6.—OLD AND NEW PARTS OF S.S. "MILWAUKEE" AFLOAT BEFORE BEING JOINED TOGETHER.

Probably the only instance in which the two ends of a ship have pointed in the same direction.

instance after instance of proud ships being overtaken with disaster and returning crippled to port after having been liberated by brave salvors from the grip of the rocks, where, perhaps, they have lain for many weeks battered by the force of angry gales; or we might tell how the skill of the shipbuilder and repairer once more makes the vessel—

which after collision had to return to port leaking like the proverbial sieve—stout and strong, and ready to "laugh at all disaster;" but space will not permit. We shall conclude this section of the article by presenting our readers with a reproduction

The "Mabel Grace."

(Fig. 7) of a photograph (one might almost be inclined to doubt that it was a genuine photograph) of the bows of the paddle-steamer *Mabel Grace,* after having been in collision when travelling about twenty-one knots an hour. The vessel was also damaged by fire through the capsizing of the cabin stoves at the moment of the collision. It was found necessary to cut off about forty feet from the steamer's length forward and replace it. The work of renewal and repairs, which included a complete overhaul of the engines and boilers, as they had been disturbed by the shock of the collision, was carried out by the Thames Iron Works Company.

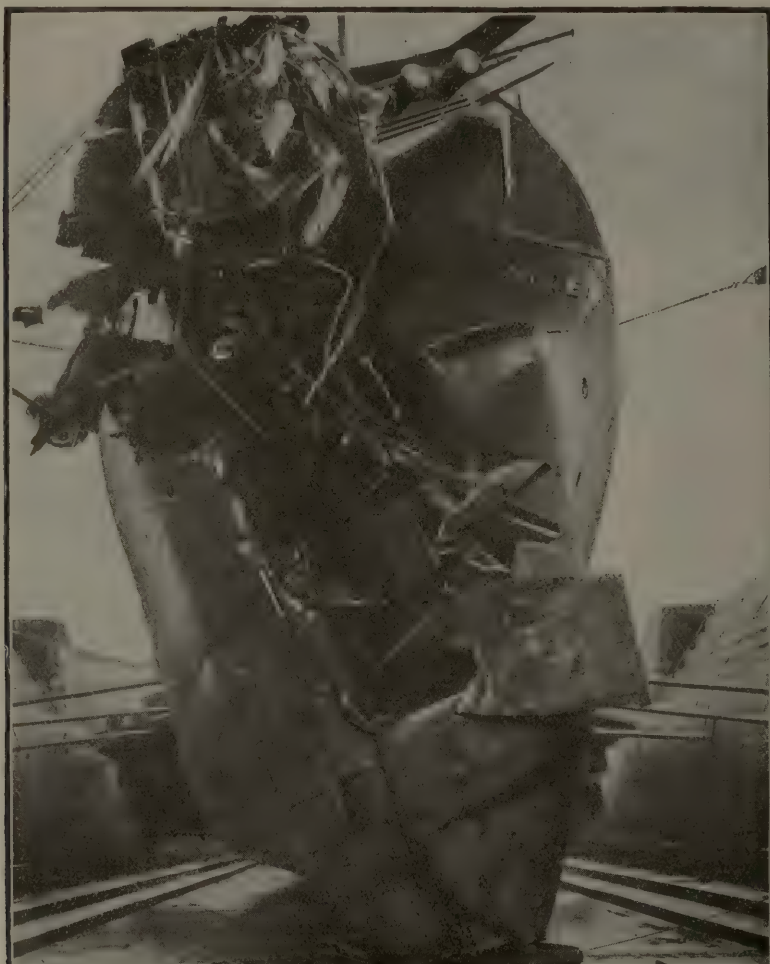


Fig. 7.—THE "MABEL GRACE" IN DRY DOCK AFTER COLLISION.

RAILROADMEN REPELLING AN ATTACK BY INDIANS.

THE CONSTRUCTION OF THE FIRST AMERICAN TRANS-CONTINENTAL RAILROAD.

BY G. L. FOWLER,

Member of the American Railway Master Mechanics' Association.

SEVENTY years ago the country lying west of the great Missouri River was practically an unknown country, in which very little interest was taken by the population of the Eastern States. California, on the Pacific Coast, was part of Mexico. To reach it meant a weary sea voyage of several months round the stormy Horn, or a toilsome land journey across plains and deserts tenanted only by hostile Indians, who hovered continually on the flanks and in front and rear of the canvas-covered, ox-drawn wagon. In the very early days of the nineteenth century, Lewis and Clarke made their famous expedition across the continent, reaching the Pacific at the mouth of the Columbia River. Daring hunters like Jim Bridger, Jacques Laramie, and the "Pathfinder"—General John C. Fremont—followed, and in 1832 a white man first took a team over the continental divide.

Asa Whitney.

As early as 1830, Asa Whitney began to dream dreams of a great railroad running from ocean to ocean, which should pour the riches of China, Japan, and India into the lap of the population of the Atlantic coast. Unable to realize that his schemes were far ahead of their time, he wasted his wealth in vain attempts to gain the popular ear, and died a poor man. More practical than Whitney, Brigham Young led his band of Mormons in 1847 across the great desert, and founded Salt Lake City, thus establishing, as it were, a half-way house for a trans-continental route. In the following year a treaty was ratified between the Governments of the United States and Mexico, by which the whole of upper California was ceded to the United States.

Then followed the gold discoveries of 1849. Far-away California, a name scarcely yet heard of by the mob, jumped into fame as an El

IN THE PRAIRIES, UNION PACIFIC RAILROAD.

Dorado. Thousands of gold-seekers rounded the Horn, crossed the isthmus, and pushed across the great American desert and the rugged steeps of the Rockies and Sierras. It is said that one hundred thousand souls used the old desert trail yearly—the Overland Route, as it came to be called. Towns sprang up on the line of march of the long wagon trains of emigrants; coach services were run more or less to schedule; the Pony Express was established. Those were spacious times, replete with stories of the outlaw's gun and the Indian's scalping knife, of terrible hardships cheerfully undergone by enthusiasts, who saw the glitter of gold in every grain of sand, or a wealth of agricultural productiveness in every sheltered valley.

Gold Discovered in California.

The Overland Route and the Pony Express were not sufficient to meet the requirements of the travelling public. In 1855 the Panama Isthmus Railroad was opened, and yielded a golden harvest to the promoters. It deflected much of the desert traffic.

The Panama Railroad.

Meanwhile the Government was waking up to the need for a means of reliable and quick communication with California. All through the 'fifties, while the tumult of pro- and anti-slavery feeling was creating a turmoil in the settled sections of the country, scouts and engineers searched the mountains for passes that should make the building of a railroad a possibility. This was done not only by the Government and the men inter-

Surveys across the Continent.

ested in the promotion of the trans-continental railroad, but by the employees of other systems building westward from Chicago. These last did not expect or desire to compete for the construction or to gain control of the Pacific Railroad, but wished to know the point from which it would jump off at the eastward end, so that they might aim their own pioneer lines, which were reaching out like long tentacles from points of vantage in the middle west towards that point, and make connections of great value when the work was done. Up and down the prairies small bands of surveyors ran their lines, at all latitudes between the Gulf of Mexico and the Canadian border line—most thickly along the forty-second parallel, near which over twenty-five thousand miles of reconnaissances are said to have been made. On the whole the country was open and rolling, with a constantly ascending grade from the Missouri to the Rockies, easy for the location of transit lines and offering few engineering difficulties as we look upon them to-day. But this whole territory swarmed with savage Indians, whose delight it had been for years to cut off the emigrant train, stampede the horses and cattle, murder the men, and capture the women and children. Hence the small parties of engineers working backwards and forwards offered the same inducement to bloodshed and theft, and few would have escaped had it not been for the guard of cavalry that was furnished. All through the reports of the engineers we read of Indian hostilities, of the unsettled state of the country, and how certain reconnaissances had to be given up because of the insufficient garrison at Government posts.

Indian Hostility.

As a result of the preliminary surveys it was decided that Omaha, on the western bank of the Missouri, must be the starting-point. But for a time nothing was done. Various events conspired against a scheme for a trans-continental railroad coming to a successful issue. Sectional jealousies, arising out of the slavery question, prevented a definite marking out of the actual line to be taken. The South would find no money for a Northern route; in the North no capital could be raised for a Southern line.

Politics eventually helped matters, however. In 1861 a few small merchants of Sacramento organized the Central Pacific Company (now merged into the Southern Pacific) to carry a track eastwards to the boundary of California to meet a line which, they urged, should be built westwards from the Missouri. The Sacramento merchants received support from intelligent opinion in the Eastern States, where, apart from the lure of the supposed Asian traffic that a trans-continental track would create, it was now realized that the isolation of a single state had its dangers. The building of the suggested railroad would bind California more closely to the Northern—anti-slavery—interest, and would enable the United States to repel with greater promptness any attack on the coast ports, and to control the Indian outbreaks which at times assumed serious proportions.

The Central Pacific Company.

Accordingly, in 1862, Congress subsidized corporations to build the Union Pacific and Central Pacific Railroads, starting from Omaha and Sacramento respectively. The United States Government undertook to issue to the said corporations thirty-year bonds, bearing 6 per cent. interest, to be delivered in blocks as each forty miles of track was completed, examined, and accepted. For the plain divisions the subsidy was fixed at $16,000 per mile; for mountain divisions, at $48,000 per mile; and at $32,000 per mile for the desert divisions, where, though the "going" would be easy, the transport of men and materials would prove a difficult and costly business. In addition, alternate sections of land flanking the railway were allotted to the promoters.

The Charter of 1862.

LIMITED EXPRESS NEAR GRAND ISLAND. *(Photo, Union Pacific Railway Company.)*

So the scheme was launched. But though men approved with their mouths and on paper, the needful capital for starting operations was not forthcoming in adequate quantities. At last, however, amid the waving of flags and firing of guns and speechifying, the ground was broken at Omaha, Nebraska, on December 3, 1863. A commencement had already been made at the western end by the Central Pacific Company.

A Start and a Halt.

The money available was soon exhausted, and a long pause ensued. We must not lose sight of the fact that the United States were at this time in the throes of the Civil War. In the Eastern and Southern States fierce battles were being fought, and money was being poured out to keep the Northern army in the field. Little wonder, then, that even so important an enterprise as this great railroad hung fire for lack of funds. But Congress, having put its hand to the plough, did not look back. To attract capitalists, it amended the original charter in 1864, doubling the land grant. After some months of scraping and scratching for money, enough was collected to permit a second start in 1864. Once more the exchequer became depleted, and the Government, as a last resort, gave permission for the organizing of a construction company, which should finance the undertaking and have a first mortgage on the property. In this way the sinews of war were provided.

The Second Charter.

Be it understood that in the early 'sixties Omaha was not yet in direct railway communication with the Eastern manufacturing states, and that as a result supplies had to be brought round to Omaha by water at great expense. We are told, too, that the engineering of the finances by the construction company—to its own undue profit—was hardly less wonderful than that required for the most difficult sections of the track.

However, in 1865 a fair and last start was made at the Missouri end. During this year about 40 miles of rails were laid, and the first instalment of the subsidy paid over by Government. Engineering difficulties were small eastwards of the Rockies. From Omaha the road climbs to the top of the intervening high ground, and then cuts across to the valley of the Platte, which it follows to the Forks, 290 miles from Omaha. Thence it runs along the south fork of the Platte to Julesberg, 372 miles. In this stretch there is a long steady climb following the grade of the river, and rising from an elevation of 967 feet at Omaha to 2,830 feet at North Platte at the Forks. It is generally conceded that, from an engineering point of view, it would have been advantageous to carry the line along the North Platte and Sweetwater to South Pass, and down the Snake River and Columbia River to Portland. This would have been a longer route, however, and as the road had to be built through almost unexplored country, wherein it was not expected to develop a local business, shortness was of prime importance with funds so hard to get, and every foot adding to the total cost.

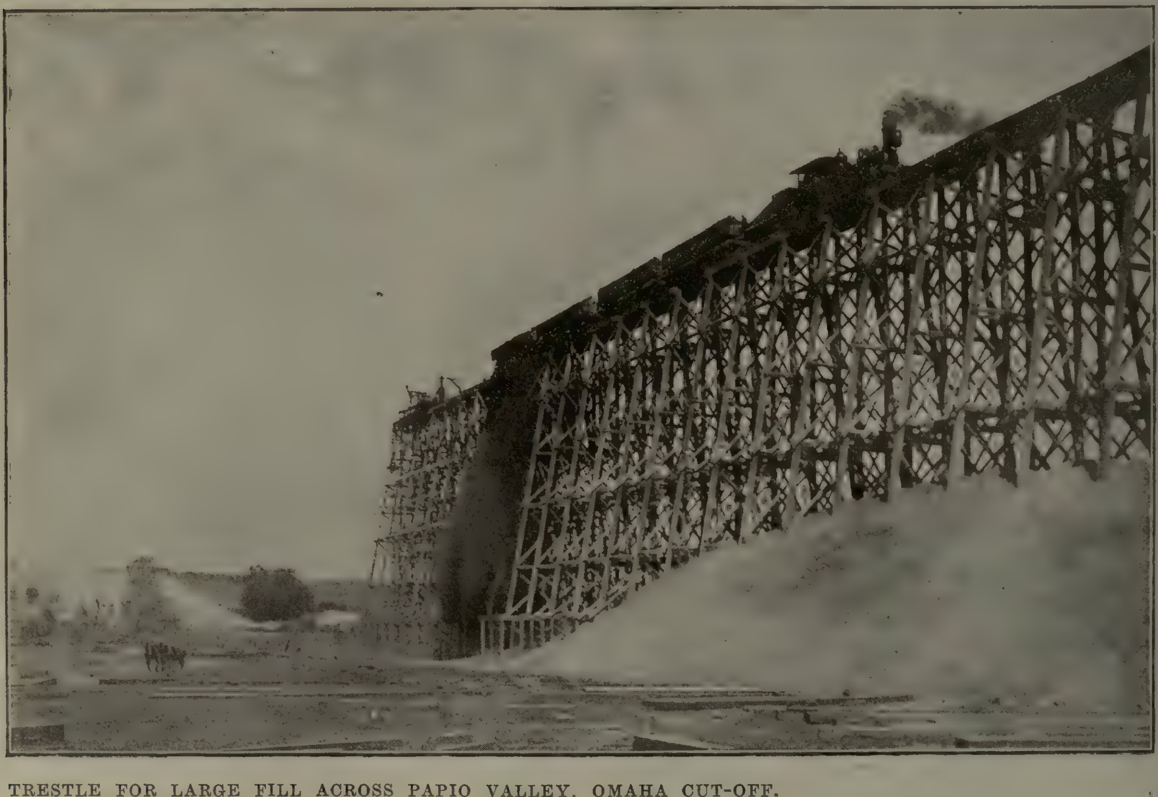
The Railroad leaves Omaha.

In 1866 the Union Pacific Company laid 260 miles of track; in 1867, 240. This brought rail-head to Cheyenne and the edge of the Rockies. The difficulties of the mountain passes began to crowd upon the engineers, and the work of location to increase correspondingly. It was no longer a question of following the easy grades of a prairie river, but of surmounting granite hills at the prescribed grade of 116 feet to the mile.

In the Rockies.

Reconnaissance and scouting had to be carried out over a wide belt of territory before the proper location could be obtained. Sometimes it seemed as though accident and chance had much to do with the final selection. Yet diligent search, hard work, and danger always preceded success. Take the case of the discovery of the route to Sherman Pass in the Rockies by General Dodge, chief engineer of the railroad. In his narrative of the episode Dodge says: "While returning from the Powder River campaign [1864–65] I was in the habit of leaving my troops and train, and, with a few men, examining all the approaches and passes from Fort Fetterman south over the secondary range of mountains known as the Black Hills, the most difficult to overcome with proper grades, of all the ranges, on account of its short slopes and great height. When I reached the Lodge Pole Creek, up which went the overland trail, I took a few mounted men—I think six—and with one of my scouts as guide went up the creek to the summit of Cheyenne Pass, striking south along the crest of the mountains to obtain a good view of the country, the troops and the train at the same time passing along the east base of the mountains on what was known as the St. Vrain and the Laramie trail. About noon, when in the valley tributary of the Crow Creek, we discovered Indians, who at the same time discovered us. They were between us and our train. I saw our danger, and took means immediately to reach the ridge and try to head them off, and follow it to where the cavalry could see our signal. We dismounted and started down the ridge, holding the Indians at bay, when they came too near, with our Winchesters. It was nearly night when the troops saw our smoke signals of danger, and came to our relief; and in going to the train we followed the ridge until I discovered it led down to the plains without a break. I then said to our guide that, if we saved our scalps, I believed that we had found the crossing of the Black Hills. And it is on this ridge between Lone Tree and Crow Creek that the wonderful line over the mountains was built. For two years all explorations had failed to find a satisfactory crossing of this range." Not only had a crossing been found,

The Perils of Surveying.



TRESTLE FOR LARGE FILL ACROSS PAPIO VALLEY, OMAHA CUT-OFF.
DUMPING EARTH FROM TRESTLE TO FORM EMBANKMENT, OMAHA CUT-OFF.

(*Photos, J. E. Stimson.*)

but one that permitted a grade of 80 feet to the mile instead of the 116 feet allowed in the Government agreement, and enabled the company to make large profits out of the high subsidy granted for the mountain division. The chief obstacle was the driving of four tunnels with a total length of 1,792 feet. Of these, No. 2, in Echo Cañon, 972 miles from Omaha, and 772 feet long, had to be commenced in July 1868, when rail-head was still 300 miles to the eastward, so as not to delay the laying of the rails when the locomotives reached the place. The local stone was unsuitable for lining purposes, and as all available transportation was required for handling tools, materials, and provisions, no stone could be brought from elsewhere, so the tunnel had to be lined with timber. Though the men worked hard, the graders were upon them before they had won through. The engineers, in order to get the line past the block, constructed two Y-shaped necks on the mountain side. The train passed up one leg into the neck—which was long enough to hold a train—and then backed out up the other leg to the second Y, where the engine got in front once more.

Sherman Pass discovered.

Tunnels.

At tunnel No. 3, driven through black limestone and quartzite, the engineer in charge decided to use nitro-glycerine instead of powder. Though some of the men struck, on the ground that two shifts could now do the work that formerly required three, the change of explosive effected a saving of $40,000, and, what was even more important, enabled the tunnel to be put through in time.

Apart from the actual engineering difficulties were those arising out of the great distance separating the workers from Omaha, the base of supplies. The wages demanded by the men—often in advance—were vastly in excess of those paid for similar service elsewhere. There was no coal, wood, or fuel of any other sort on the plains, and no timber to make sleepers of, so that many of the last cost the company ten shillings each. The workmen were discouraged by the barrenness, and grew weary of the cloudless sky and dry white earth, and the lack of supplies of fresh food.

High Cost of Materials.

But probably the greatest trouble in the Rockies division arose from the frequent attacks by Indians. It has been said that an Indian arrow was shot for every spike driven into a tie. That may be only a picturesque exaggeration; yet it is a fact that the annals of the construction period are filled with accounts of desperate fights between the track-layer and the war-painted Redskin. The Indians had not molested Brigham Young's party, and had done comparatively little damage to the trains of the "'forty-niners" hurrying to the Californian goldfields. But when the white man came with his trail of steel and iron horse, and was guilty of ruthless and wanton destruction of the buffalo—the source of Indian food and clothing—the savage went on the war-path with a craft and pertinacity that soon made it necessary to send troops to protect the workmen. These last were themselves, in many cases, old soldiers who had seen service during the Civil War; who were as ready to fight an Indian as to lay a tie or fix a spike; who at a word of command would fall in, deploy as skirmishers, and repel an attack, and then return calmly to their work. They formed, with their twofold qualifications, an army of the pick and rifle that thought little of danger. It was the latter trait—contempt of perils with which they had become familiar—that accounted for a large proportion of the entries on the death-roll. It is interesting to note that the Pawnees, who had been treated very badly by the Sioux, took the white man's side, and proved of no little value in checkmating attacks.

Indians on the War-path.

While the Union Pacific Railroad was being

UNION PACIFIC TRACK WEST OF LAWRENCE STATION.

pushed ahead, the Central Pacific also progressed rapidly. Starting from Sacramento, about 140 miles from San Francisco, it commences at once to climb the Sierra Nevada, and in 105 miles attains an elevation of over 7,000 feet at Summit, without any undulations of the track, and by a constant rise from the foot-hills to that point. A peculiarity of the route is the fact that the engineers have taken advantage of a bold ridge which runs out from the main chain of mountains, and reaches nearly to Sacramento, just as the ridge at Sherman Pass on the Union Pacific runs from the Rockies down to the plains. By following this ridge all the way up to the sources of the South Yuba, an excellent natural grade was obtained, broken by but few ravines, and having a uniform and continuous ascent. Such another path across the mountains is not to be found for hundreds of miles up or down the range, and, in all of the passes used by wagons the mountain side is too precipitous to be suitable for railway purposes.

Progress of the Central Pacific.

From the valley of the South Yuba across to the Truckee River, the deep snow belt, thirty-five miles broad, is met. For the greater part of this distance the road follows a side-hill line, which for the most part is so sheltered as to be available for winter traffic. Here the snow-sheds are located, and between them are embankments and tunnels,

The Snow Belt.

so that the line is kept open all the winter through without an excessive amount of labour. The amount of snow that falls in the Sierras is at times enormous. In the winter of 1866–67 there were forty-four snowstorms, varying from a short squall, with its quarter of an inch of snow, to a gale lasting a fortnight, and depositing a ten-foot blanket. The freshly-fallen snow was very light, and impassable except on snow-shoes. It lay for a long time. One of the constructing engineers related how in June a road had to be cut through a twenty-five feet drift in weather so warm that within a week watering carts were being used to lay the dust on the road between the partially melted banks of snow.

High Elevations.

The courage required to put a line through this country can hardly be appreciated to-day. It must be remembered that in 1863, when the road was started, there were no precedents for a work of this magnitude, especially at such elevations, which were more than twice as great as any yet attained by a railway in the United States. The following table of elevations on the Central Pacific is instructive :—

Between sea-level and 1,000 ft. altitude,		31½	miles of track.	
,,	1,000 ft. and 2,000 ft.	,,	14	,, ,,
,,	2,000 ft. and 3,000 ft.	,,	16	,, ,,
,,	3,000 ft. and 4,000 ft.	,,	22½	,, ,,
,,	4,000 ft. and 5,000 ft.	,,	460	,, ,,
,,	5,000 ft. and 6,000 ft.	,,	125½	,, ,,
,,	6,000 ft. and 7,000 ft.	,,	55	,, ,,
	Above 7,000 ft.	,,	1½	,, ,,

Experience has shown that the snows are not the formidable obstacle that they were expected to be, and has justified fully the good judgment of the engineers in carrying the line where they did. The tunnels on the Central Pacific aggregated 6,213 feet, the longest item being but 1,658 feet. On the other hand, many miles of snow-sheds—artificial tunnels, in fact—had to be made to protect the line from avalanches and earth slides.

Public Interest aroused.

From Summit to the great interior basin, which lies 4,000 to 5,000 feet above sea-level, the descent was comparatively easy. By the time that the Union Pacific had reached the eastern slopes of the Wasatch Mountains and the Central Pacific builders

TRESTLE OF LUCIN CUT-OFF. (*Photo, J. E. Stimson.*)

FILLING IN FROM TRESTLE ON LUCIN CUT-OFF. *(Photo, Southern Pacific Railway Company.)*

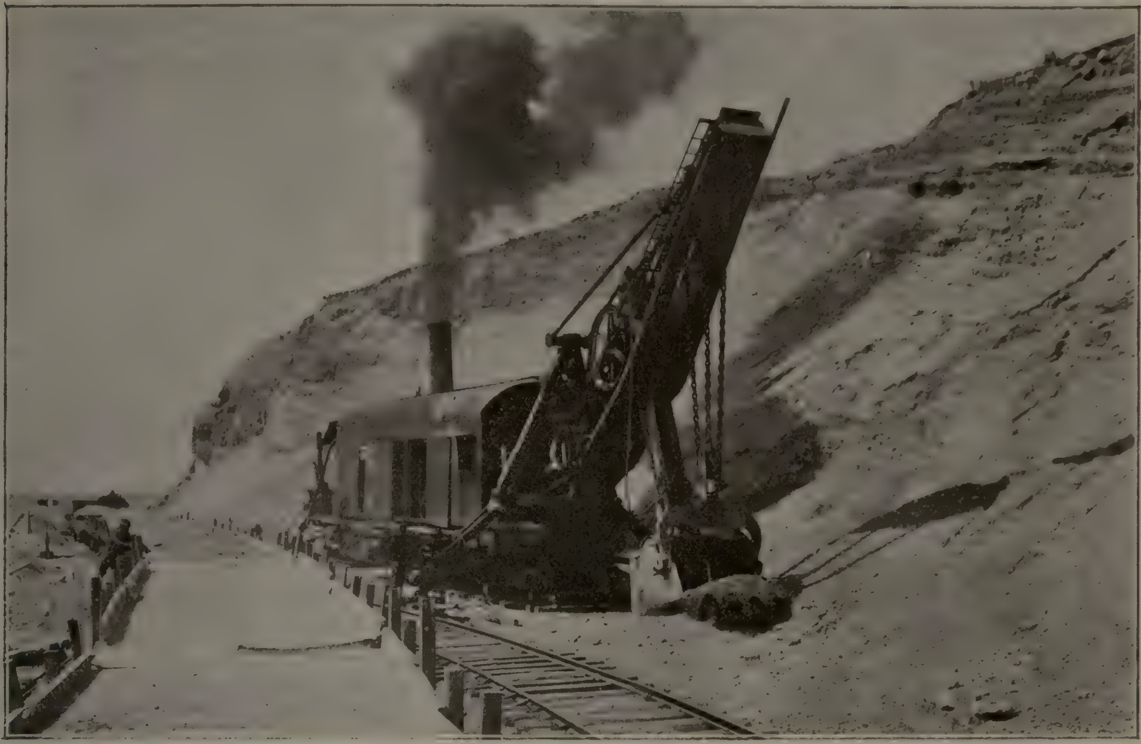
were approaching the Great Salt Lake, public interest in the coming completion of the track increased greatly. Special correspondents flashed messages from the "front" to their respective journals, giving particulars of the daily advance.

The railway builders had now to decide whether they should pass to the north or to the south of the Great Salt Lake, a body of water over 80 miles long. If the north were selected, the city of the Mormons would be left on a branch line. It was preached from the pulpits that the line must take the southerly route; the railway surveyors announced that the northerly route was vastly preferable. Then the head of the Mormon Church, Brigham Young, issued an edict forbidding his people to contract or work for the Union Pacific, and exerted his great influence on behalf of the Central Pacific, which was creeping towards the lake, in hopes that it might be induced to pass at the southern end. But his expectations were disappointed by the physical features of the country. The Central Pacific's explorations confirmed the decision of the Union Pacific—to go north. So the Mormons accepted the inevitable, and assisted the completion of the work, which would at least bring them much nearer than before to centres of civilization, by means of a fifty-mile branch track.

Anxiety of the Mormons.

At Ogden, about twenty-five miles east of the lake, the two lines were to have met. But the Union Pacific, getting there first, and being anxious to earn the subsidy, pushed on. The Central Pacific folk, urged by the same desire, in turn carried their rail-head past that of their rivals. So there was seen the extraordinary spectacle of two tracks being graded parallel to one another, one of which would be of no value whatever. When this stupid business had been persisted in until the

The Grades overlap.



STEAM SHOVEL AT WORK, PROMONTORY POINT, SALT LAKE.

"overlap" was some two hundred miles long, the Government stepped in, and decided that the rails should be joined at Promontory, north of the lake.

The Last Spike.

May 10, 1869, was the great day in the history of the first trans-continental track. On that day a small excursion party came from San Francisco to witness the crowning ceremony of driving the last four spikes, two of gold, two of silver, into the last tie—of highly-polished Californian laurel. Just before noon the tie was brought forward and placed in position. At the stroke of the hour, after a short prayer by a clergyman present, the silver hammer dropped, and the signal was flashed over the telegraph to Eastern centres, announcing that the track was complete, seven years ahead of time. New York city rang the Old Hundredth on its church bells, and fired a salute of a hundred guns. Chicago paraded. Omaha turned out *en masse*. San Francisco, which had begun the celebrations two days too soon, made matters square by prolonging them for two days after the event.

Cost and Quality.

The first total cost of the joint railroads was officially returned at 115,214,587 dollars, 79 cents. As regards value for money, the location and construction of the Union Pacific portion were, on the whole, good. This was partly due to the fact that before the Government subsidies were paid the road had to be approved, and plans approved before construction began. The second condition involved some injustice to the engineers, who were more competent to decide what was the proper course to take in certain circumstances than were officials who entered the country for the first time when they came to inspect work that had been done. The suggestions made by the officials were often wrong. At their instructions the grade was levelled over

OVERLAND LIMITED ON LUCIN CUT-OFF TRESTLE. (*Photo, Southern Pacific Railway Company.*)

the Laramie plains by cuts in the undulations of the ground. When winter came the cuts were blockaded by snow, and they had to be refilled subsequently at a cost of between five and ten million dollars. Experience taught the Government to worry the engineers less and less as the work proceeded, and to trust General Dodge to take the best line. How thorough the general was in his surveys is shown by his own words. "We had to study every summit, every mountain side, every valley, to find from the currents which was the snowy side and which the barren; and over the whole 1,500 miles of line located, for three winters we kept the engineers in tents or dug-outs watching, from four to six months, the drift of snow and water to be overcome, and the safest, surest, and most effectual methods of doing it."

The report issued by the Government Commission in 1869 made some severe strictures on the location of the Central Pacific through the Sierra Nevada. The curvature was excessive and needlessly sharp. Throughout a large portion the ascents and descents had been multiplied needlessly. Grades of 70 to 80 feet per mile had been introduced where one of 53 feet per mile would have sufficed, and grades of 53 where not half that rate of ascent was required. In the Humboldt Valley, between Humboldt Lake and Humboldt Wells, the difference in elevation of a little over 1,100 feet had been overcome by ascents and descents amounting to 6,232 feet in a distance of 290 miles.

Criticisms of the Central Pacific.

In justice to the builders, it must be remembered that at the time when the line was located and construction carried out, the facilities of the present day were not avail-

able to the contractor and engineer. The principles of railroading had still to be learned in large part. Now it is cost of operation that is looked to. Grades must be kept down to the minimum and curvature eliminated if possible, so that the heavy tonnage of the later-day train may be hauled at least expense. The steam shovel, the air drill, and dynamite make excavations and tunnelling far easier than they were forty years ago. If a hill or a mountain intervenes on the route selected, it is levelled or tunnelled, and the easy-grade line adhered to. In 1862 the means of effecting such work easily did not exist, and engineers were accustomed to avoid obstructions rather than fight them. They skirted hills and climbed over mountains to avoid high cost of construction. Though we may now regard the stretch between the Missouri and the Rockies as "easy" country, it was not so very easy when every yard of earth removed represented the work of a man with shovel and pick.

Engineering Handicaps.

A good deal of improvement was purposely left to the future, when traffic developments should justify the expense. By the year 1900 the traffic demanded that the present management should take the task of reconstruction in hand—of tearing up the old track and replacing it, of abandoning sections altogether, of tunnelling mountains to avoid curves and severe gradients, of replacing wooden bridges with steel.

Improving the Track.

From a point on the main track in the west part of Omaha, known as the Summit, to Lane, a small station due west from the city, the direct distance is about twelve miles. The line taken originally by the railroad be-

SUNSET AND OVERLAND LIMITED CROSSING SALT LAKE. *(Photo, Southern Pacific Railway Company.)*

SNOWSHED ON SOUTHERN PACIFIC, CALIFORNIA.

tween these points has a length of almost twenty-one miles. The "Omaha Cut-off," completed recently, takes the air-line route. The country is rugged and rolling, and the hills are of a friable material known as "loess." The drainage runs north and south, practically at right angles to the line, and there are no favourable water-courses for the line to follow to secure lighter earthwork. With the exception of a few curves necessary to connect with the old main line near Summit, and for a similar purpose at the west end, the alignment is straight, running over hills and valleys regardless of topography and expense. To build this line involved 2,800,000 cubic yards of excavation and about 4,000,000 cubic yards of embankment. In one case, in the crossing of Big Papillon Creek, the embankment is 65 feet high and 5,600 feet long, and, with a width of 300 feet at the bottom, contains approximately 1,500,000 cubic yards. Another fill across the Little Papillon is 89 feet high and 3,100 feet long. In this case the original width at the bottom was estimated to be 320 feet. But in the bottom of the valley the soil is very soft, and rose up on each side of the embankment as the latter settled, adding nearly half a million cubic yards to the first estimate.

The Omaha Cut-off.

An even greater work than the Omaha Cut-off is the "Lucin Cut-off" over the Great Salt Lake. The original route ran, as we have seen, from Ogden round the north end of the lake, round many curves, and up the heavy grades required to surmount Promontory and Kelton Hills. A short line along the north shore of the lake was out of the question, because of the extreme irregularity of the same.

TELESCOPIC SNOWSHED, SHOWING MOVABLE LENGTH PUSHED BACK INTO LARGER SECTION.
This arrangement makes it possible to isolate a snowshed fire, and in summer to give travellers a better view of the scenery.

The Lucin Cut-off.

So the reconstructing engineers decided to build a straight cut-off from Ogden across the two northern arms of the lake and the promontory which separates them, to Strong's Knob on the west shore, and thence to Lucin over an easy grade. The total length of the cut-off is 102·5 miles, a saving of 43·5 miles over the old route.

The new line has a maximum grade of 21 feet to the mile. From the promontory to Strong's Knob it is level and almost straight. The fall from Ogden to the east shore is 100 feet, and the rise from Strong's Knob to Lucin only 200 feet in 52 miles. Both of these allow of very easy grades, the country being quite level. There are two slight curves, but the whole section from the promontory to the Knob is only 26·3 feet longer than the air-line distance.

A Great Feat of Engineering.

The line is practically free from those engineering obstacles which are generally found in a mountainous region; yet it presents something new to the engineering world—a feat found in the execution to be full of difficulties and surprises. The distance from shore to shore is about 22 miles, all of which is trestle and embankment in the lake except the short stretch of cutting across the promontory. The distance between the east shore and the promontory is, roughly, 8½ miles, and over part of this the water has receded, leaving a bed of mud which was in many places from 8 to 10 feet thick under the salt crust. Great variations in the consistency of the lake bottom were encountered during the driving of the piles for the trestles. At times a blow of the "monkey" did not sink the pile more than an inch or two; at others a

A SWITCHBACK IN THE MOUNTAINS.
CONSTRUCTION WORK, CASCADE BRIDGE, CALIFORNIA.

single impact would send it down as many feet. Again, a succession of blows might seem to be without effect, the pile having struck a hard stratum. Suddenly this would give way, and the pile would drop several feet. It often happened that a pile, after having been driven in from 30 to 50 feet, would rise a couple of feet between the blows of the driver.

Pile-driving.

In one place a really serious difficulty was encountered. The first pile, 26 feet long, was driven out of sight with a single blow. A second pile, 28 feet long, set on top of the first, also disappeared in like manner. Upon examination it was discovered that the mud deposited by the Bear River, flowing into the lake from the north, had accumulated here to a depth of 50 feet. To overcome the difficulty trestles were made of two 40-foot piles spliced end to end, and on them were laid the rails to carry the trains while rock was being dumped in between the trestles to form a solid embankment. The last part of the business, the filling with rock, took a long time, as the material broke through the salt crust, and had to be piled up from the firm bottom below it. A forest of two square miles' area was felled to supply timber for the job, which cost at least eight million dollars from first to last. Apart from the reduction of distance, the curvature saved by the new line would be enough to turn a train round eleven times; while the power saved in moving a train, owing to the smaller mileage, is equal to that required to haul the weight of a single passenger four hundred times from New York to San Francisco.

Difficulties.

In addition to the two cut-offs described above, some very long tunnels have been driven through the mountains to reduce grades and distances. The Central Pacific has been practically rebuilt. More than 13,000 degrees of curvature, and 3,000 feet of rise and fall, have been eliminated.

After the completion of the track the Union Pacific leased its portion to the Central Pacific, which was afterwards absorbed by the Southern Pacific system. The promoters discovered that but little revenue came to the corporations from through traffic with the east, and that they would have to depend upon local traffic for remuneration. Unfortunately, while the country was being opened up, the railroad starved, and passed into the hands of receivers. The stock values fell almost to vanishing point. Then the late Mr. E. H. Harriman took the Great Trans-continental in hand, threw all his extraordinary energy into making it pay, and now the ordinary stock is quoted at about a hundred per cent. above par, in spite of the enormous sums spent on the reconstruction of the track.

Recent History of the Track.

The Union Pacific has done a wonderful work. It has changed the nature of the country through which it passes. Omaha has become the third place in the United States for packing meat products. Fremont has sprung from nothingness into a prosperous and beautiful city of ten thousand people. As the "Limited" passes westwards it traverses what was once prairie and is now a great agricultural district, dotted thickly with snug farms, capacious barns, and active windmills. An area that produced nothing fifty years back now exports produce worth half a million dollars, excluding live stock and minerals. Lexington, where, in 1867, the Southern Cheyenne Indians burned a freight train, is now a town of 25,000 people, surrounded by fertile irrigated fields. Laramie is given over to railroad shops and to mining. From Granger branches off the Overland Route to Portland, Seattle, Tacoma, and Spokane. Dropping down through the wonders of Echo Cañon—waterfalls, frowning cliffs, turrets, and domes of weather-worn rock—we reach Ogden,

What the Overland Route has done.

DRIVING PILES OF RAILWAY TRESTLE ACROSS THE SOUTHERN ARM OF SAN FRANCISCO BAY.

(Photo, Southern Pacific Railway Company.)

CONSTRUCTION WORK BETWEEN SUMMIT AND BLUE CAÑON, CALIFORNIA.

which has become important as the junction for Salt Lake City. The increase of population in Utah has made the wilderness blossom, and discovered the enormous mineral wealth of the hills. Salt Lake City is now probably the greatest smelting centre of the world, and the once-named "Great American Desert"—marked in maps of 1850 as "unexplored territory"—laughs with harvests.

Conclusion.

So into the Sierras, passing right and left thriving mining centres, to Truckee, where the Government has invested several million dollars in irrigation works, and won many thousand acres from barrenness. Higher up we enter the snow region, and presently drop towards the Pacific, through marvellous scenery, into the Sacramento Valley, the land of sunshine and orchards, and reach the capital town, where the Central Pacific scheme was hatched. From Sacramento we have a choice of routes to the great gateway of the west, San Francisco, where our journey ends, and with it this brief narrative. The Overland Route is no longer the only highway between the Eastern and Western States. Since that May day of 1869 other trans-continental lines have been completed. But none of them equals in daring and in interest the first iron road, which showed the way to others, and remains as a monument to the enterprise and tenacity of its promoters.

THE WONDERFUL CURVES ON THE ST. GOTHARD RAILWAY AT WASSEN, IN THE VALLEY OF THE REUSS.

The line is seen at three different levels.

(*Photo, Swiss Federal Railways.*)

THE GREAT TUNNELS THROUGH THE ALPS.

THE huge elevated masses of the Alps form what is undoubtedly the most important physical feature of the European continent. In them rise most of the great rivers of Central and Western Europe. Their opposition to the passage of wind currents regulates in large degree the climate of the countries in their immediate neighbourhood.

Not less important are their political effects. But for the obstacles thrown by them in the way of movements of human beings, the history of Europe would have been very different. By the Alps, Italy is separated on the north from France, Switzerland, and Austria. They interpose an almost complete ring fence between Switzerland and France, Italy, Germany, and Austria. In short, the Alps are, and always have been, the dividers of European nations. Here and there occur breaches in the barriers, through which have marched invading hosts—Carthaginians, Romans, Goths, Huns, French, Germans, Austrians—through which has been

The Alps.

maintained the kindlier traffic of commerce. Splendid roads were constructed over the passes by military engineers—by the Romans first, and, many centuries later, by the great Napoleon. Early in last century regular stage-coach services were established, and, except in winter, served the needs of the comparatively small travelling public.

Presently came the development of the railway. Tracks crept up from all points of the compass, but on reaching the Alpine slopes had in most cases to stop abruptly. The first line to cross the Alps was the Semmering Railway, which in the years 1848–54 was led over the Semmering Pass, to open direct communication between Vienna and Austria's greatest seaport, Trieste. The Semmering Pass lies in one of the Alpine offshoots. At the crest a tunnel had to be driven through nearly a mile of rock; otherwise the work was confined to bridging, cutting, and filling.

The Semmering Railway.

Soon after the completion of this enterprise the French began to busy themselves with a much more ambitious project—that of piercing the Col de Fréjus, about 18 miles south of Mont Cenis, with a double-track tunnel, nearly eight miles long, which should be the last link in the Victor Emmanuel Railway, and bring Paris within eighteen hours of Turin by rail. At that time trains ran on the French side to Modane, whence passengers and baggage had to be taken fifty miles by road—later, by the Fell surface railway—over the mountains to the terminus, at Susa, of the railway on the Italian side.

The Mont Cenis Tunnel.

An agreement was made between the French and Italian Governments whereby the latter undertook the financing of the work, but sublet the driving of the western half of the tunnel to the French for £760,000, plus a premium of £20,000 for every year less than twenty-five years, and £24,000 for every year under fifteen years saved in construction. The French Government agreed to pay a subvention of £800,000 as their share.

Great public interest was aroused by the boldness of the scheme. A tunnel of so great a length had not been attempted previously in any part of the world. The difficulties ahead could not be estimated, owing to the lack of experience in burrowing under lofty mountain peaks. As it would be impossible to sink air-shafts along the line of the tunnel, serious problems of ventilation had to be faced. At that period, moreover, gunpowder was the only blasting agent available. To sum up, the ample time limit—twenty-five years—allowed by the contracts affords sufficient proof that the driving of the Mont Cenis Tunnel was regarded as a very formidable task.

A Gigantic Undertaking.

At first boring proceeded very slowly indeed, and at the end of five and a half years only one-fifth of the work had been accomplished. The introduction of the Sommeiller compressed-air drill expedited matters, however, and seven and a half years more sufficed for completion. On Christmas Day, 1870, at 4.25 p.m., drill No. 45, working on the Italian side, knocked a bore-hole 12 feet long through the barrier of rock separating the advanced galleries driven by the French and Italian gangs. The information was telegraphed to Turin, and contractors and engineers hurried up on a special train. Meanwhile a number of bore-holes were made in the rock curtain and filled with blasting charges. When the last were fired the galleries were brought into communication; and at 5.30 p.m., on December 26, M. Copello, the engineer in charge of the works on the French side, passed from end to end of the tunnel, entering at Modane and coming out at Bardonnèche, the Italian portal. The error in direction was found to be nil, the vertical error to be one foot, and the actual length to be 15 feet in excess of

The Mountain pierced.

THE GOESCHENEN (NORTHERN) ENTRANCE TO THE ST. GOTHARD TUNNEL.
TRAIN LEAVING THE ST. GOTHARD TUNNEL AT AIROLO.

(*Photos, Swiss Federal Railways.*)

the calculated length. It need hardly be said that such results betokened extreme accuracy in the surveying operations preliminary to laying out the tunnel's centre lines.

Details.

The Mont Cenis Tunnel is 7·9806 miles long, including the two curved entry tunnels, which meet the main tunnel, 7½ miles long, some distance in from the portals used for sighting purposes. At the French end the maximum dimensions are: width, 26 feet 2¾ inches; height, 24 feet 7¼ inches. At the Italian end the width is the same, but the height is about a foot greater. The gradients from the French and Italian portals to the centre point are 1 in 45½ and 1 in 2,000 respectively. It may be added that the Modane entrance is 3,945 feet, the Bardonnèche 4,379 feet, above sea-level; that the greatest depth of rock immediately over the tunnel is nearly a mile; and that the highest temperature recorded during the work was 87° Fahrenheit.

The total cost was about £3,000,000, or £225 per yard; the average progress made per day 2·57 yards.

The opening of the Mont Cenis Tunnel revolutionized travel from France and England to Italy, and transferred a great portion of the Eastern mail and merchandise traffic from Marseilles to Brindisi and Genoa. So great were the advantages gained, that the Swiss determined to effect railway access to Italy over or through the great barrier of the Lepontine Alps.

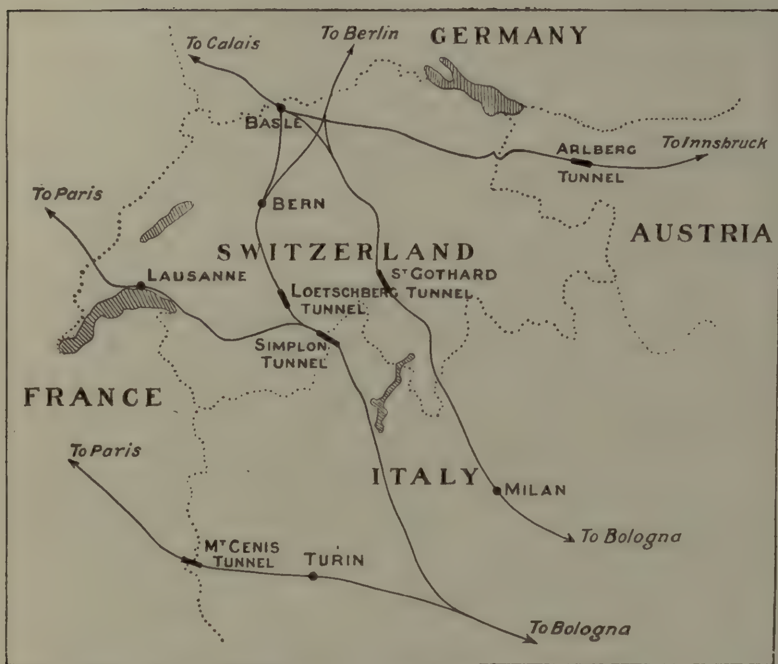
The St. Gothard Project.

After mature deliberation it was decided to take a railway from Altdorf, at the south-eastern end of the Lake of Lucerne, up the valley of the Reuss to Goeschenen, to tunnel from that point under the St. Gothard to Airolo, and so gain the head of the valley of the Ticino, through which the rails would be led down to Biasca, on the way to Lugano, Como, and Milan.

As the scheme was of importance to Italy and to Germany, these countries contributed 45,000,000 and 20,000,000 francs respectively towards defraying the cost. Switzerland came in equally with Germany; and as soon as the agreement was signed, the public subscribed a further 115,000,000 francs within twenty-four hours. M. Louis Favre of Geneva, who undertook the contract, died of apoplexy in the St. Gothard Tunnel before it was completed.

The summit tunnel was to be 9¼ miles long. This by no means represented the sum of tunnelling to be done, as in the 56 miles between Erstfeld in Switzerland and Biasca there are over 8 miles of additional subsidiary tunnels, including the three corkscrew tunnels on the north and the four on the south of

ONE OF THE STEAM LOCOMOTIVES USED ON THE ST. GOTHARD RAILWAY.



SKETCH MAP SHOWING THE POSITIONS OF THE CHIEF ALPINE TUNNELS AND THE ROUTES OPENED UP BY THEM.

the summit. From first to last the physical conditions were most difficult, the valleys being narrow and precipitous, and the gradients severe. The approaches are, in fact, as wonderful as the main tunnel itself.

The exact length of the tunnel is 16,295 yards. Its section is the same as that of the Mont Cenis. From the northern portal the rails run for 8,127·8 yards up an incline of 1 in 172, to a level stretch 180 yards long at the centre; which passed, they encounter a decline, 7,970·3 yards long, of 1 in 1,000 to Airolo, at the southern entrance.

Gradients.

Work on the tunnel began on September 13, 1872, at the southern end, and on October 24 at the northern end. The system adopted was to run top galleries in ad ance and break them out laterally and downwards to the full section of the tunnel. The Sommeiller air-drills used on the Mont Cenis Tunnel were replaced by the more efficient Ferroux drills, making two hundred strokes per minute. Moreover, dynamite was substituted for gunpowder in blasting. These improvements, added to the experience gained from the earlier tunnel, rendered progress much faster than at Mont Cenis — the daily advance a eraging 6·01 yards—and reduced the cost to £142, 13s. per yard. Bad ventilation caused so much sickness among the men that air locomotives were introduced to remove *débris* from the working face.

Improved Drills and Explosives.

On New-Year's Day, 1882, the tunnel was completed, and shortly afterwards Switzerland and Germany possessed easy communication with Genoa and other Italian ports. The time occupied in driving the tunnel had been 88 months, as compared with the 157 months of the Mont Cenis, though the St. Gothard was the longer of the two tunnels by well over a mile. The cost of this tunnel was rather more than £2,300,000 sterling.

Success.

While the St. Gothard Tunnel was still in progress, the Austrian Government had put in hand a project for giving Vienna rail communication with Paris through Switzerland, as an alternative to the partly German route *viâ* Salzburg, Munich, Stuttgart, and Strassburg, by prolonging the line to Innsbruck through Landeck to Feldkirch, near the Swiss frontier.

Westwards of Landeck the Alps assert themselves, and the line has to climb up gradients of about 2 per cent. and round numerous sharp curves. At St. Anton it enters a summit tunnel, 6½ miles long, running due east and west. For 2½ miles the gradient

The Arlberg Tunnel.

rises 1 in 500, and for the remaining 4 miles to Langen there is a decline of 1 in 66.

Work was begun on November 13, 1880. The working parties at the east end encountered hard but waterless rock; whereas at the west end the material to be pierced was micaceous and fissured, and water caused delays which about counterbalanced the greater ease of drilling. Instead of the top heading method used at the St. Gothard, the engineers employed a bottom heading run in advance at rail-level. From this, vertical shafts, or "break-ups," were made every 79 feet in the eastern, and every 216 feet in the western portion to the level of the crown of the arch, and top headings then driven both ways above and parallel to the bottom heading. This system made it possible to have 1,500 metres of excavation in hand at once. The tunnel was enlarged to full size and lined in lengths of 20 to 26 feet, the two processes requiring on the average twenty and fourteen days respectively. In section the tunnel was 26½ feet wide (maximum), and 18½ feet high above the sleepers over a width of 11½ feet. The lining varied in thickness from 1½ to 4 feet.

It was anticipated that the driving would take five full years, and the contract was based on this term, a premium of £80 a day being allowed for every day less than that period occupied. But owing to the quicker system of excavation used and to the adoption of the new Brandt drill, the headings met as early as November 13, 1883—the anniversary of the start—and the tunnel was ready for traffic ten months later. The fortunate contractor therefore earned a premium of many thousands of pounds.

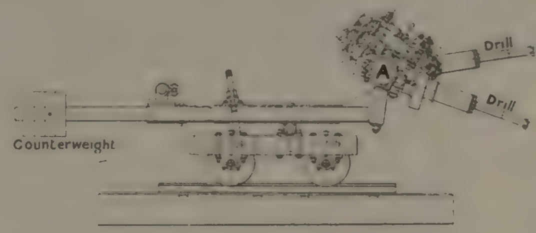
Quick Progress.

To show the advance in the art of tunnelling as exemplified by the three big enterprises noticed so far, the following comparative table is of interest :—

Tunnel.	Length.	Time in months.	Average advance per day.	Cost per yard.
Mont Cenis	7½ miles	157	2·57 yards	£215 6 0
St. Gothard	9¼ miles	88	6·01 yards	£142 13 0
Arlberg . .	6⅓ miles	43	9·07 yards	£107 13 0

The Brandt drill, which was used in the Swiss half of the Arlberg Tunnel, and, years afterwards, exclusively for the Simplon Tunnel, is worthy of more than passing mention. It differs radically from the percussive drills used previously in being driven by water instead of air, and in boring, not pecking, its way into the rock. The drill stem is hollow,

The Brandt Drill.



THE BRANDT ROCK DRILL, WHICH HAS DONE SO MUCH TO FACILITATE TUNNEL DRIVING.

A, rack bar on which the drills are mounted, and which is jammed across the heading by hydraulic rams.

as is also the boring bit. The last is furnished with three or four teeth, splayed outwards slightly, so as to make a hole somewhat larger than the stem. Two small cylinders, driven by high-pressure water, rotate the drill mandrel holding the drill through worm gearing, five to ten times a minute, and exhaust the water through a pipe leading down the hollow centre of the drill. This system keeps the drill cool, and washes out the small detritus from the face as fast as it is detached. The teeth are worn down quickly by hard rock, but re-forming, sharpening, and re-tempering them is easy work for a skilled smith. The drill is pressed against the face by a hydraulic ram, which gets a purchase on a beam wedged across the heading. The ram

has a piston area of 15½ square inches; and as the water pressure is about 1,500 lbs. to the square inch, the total ram thrust is over ten tons. To sink a hole 39 inches deep takes from twelve to fifteen minutes. Engineers who have used it maintain that the Brandt drill has done more than anything else for the progress of rock tunnelling.

THEODOLITE STATION ON MONT LEONE, 7,000 FEET ABOVE THE LINE OF THE SIMPLON TUNNEL.

(*Photo, by courtesy of Mr. Francis Fox.*)

The ventilation in the workings of the Arlberg Tunnel was good—far better than in those of the St. Gothard and Mont Cenis. Large pipes were brought up to the working faces, and from them was squirted water in fine jets after a blast explosion to lay the dust and absorb the fumes of the explosive. Also, fresh air was pumped by electrically driven pumps through other pipes and delivered where needed. Steam locomotives were used for haulage, but so constructed that the fires could be banked down and the smoke confined while an engine was inside the tunnel.

Ventilation.

From the Arlberg we pass to the longest, and in many ways the most interesting, tunnel yet constructed—the great 12¼-mile bore under the Simplon Pass. Since the time of the Romans, and probably since a date much earlier than that of the founding of Rome, the Simplon Pass has been one of the chief routes over the Alps. The present excellent but little used roadway was completed, by order of Napoleon, in 1805. It is 37½ miles long, and cost over £300,000 to construct.

The Simplon Pass.

During the latter half of last century many schemes were mooted for taking a railway through the pass. Of these, all but two included a summit tunnel. In 1879 the Jura-Simplon Railway was brought from the east end of the Lake of Geneva up the Rhone Valley to Brieg, at the north end of the pass, where it had to stop; and at about the same time the Italians had pushed a track up to Lake Maggiore. In 1881 the Jura-Simplon Company proposed piercing the mountains between Brieg and Iselle, in the narrow valley of the Diveria on the Italian side. A tunnel at this point would bring north-western France nearer to Italy, cutting off between Calais and Milan no less than 80 and 95 miles as compared with the St. Gothard and Mont Cenis routes respectively. To secure fast and cheap traffic the tunnel must be at low level, to permit easy grades on the approaches, and therefore be of great length.

Projects for a Tunnel.

SIGNAL STATION ON MONT LEONE, CAPPED WITH A CONE OF ZINC.

Many of these stations were built to assist the trigonometrical survey made to establish the centre line of the Simplon Tunnel.

(*Photo, by courtesy of Mr. Francis Fox.*)

By 1890 the scheme had advanced so far that Messrs. Sulzer, Brandt, and Brandau, as contractors, handed to the company a definite scheme for carrying through the work. This scheme was examined and approved by a commission of independent experts, and on November 25, 1895, a convention was signed between the company and the Italian Government, and ratified a few days later by the Swiss Government. Out of the estimated £3,040,000 needed for the scheme, over £810,000 was subscribed freely by local bodies in the countries principally concerned.

A Convention signed.

A WORKING ENTRANCE TO THE SIMPLON TUNNEL.

The plans finally accepted specified, in the place of the usual single large tunnel, two single-track tunnels with their axes 55·8 feet apart, and connected by cross-passages every 200 metres. In the first instance only one tunnel would be made full size, but the headings for both were to be driven simultaneously, in order to facilitate ventilation and transport. This double-barrelled system, here used for the first time, is advantageous in that the derailment of a train on one track cannot endanger the other track, that either tunnel can be repaired without interfering with the other, and that two small tunnels are much less affected by pressure than a single one of equal total section. Events showed that, had the engineers chosen the single large bore, the Simplon Tunnel could never have reached completion.

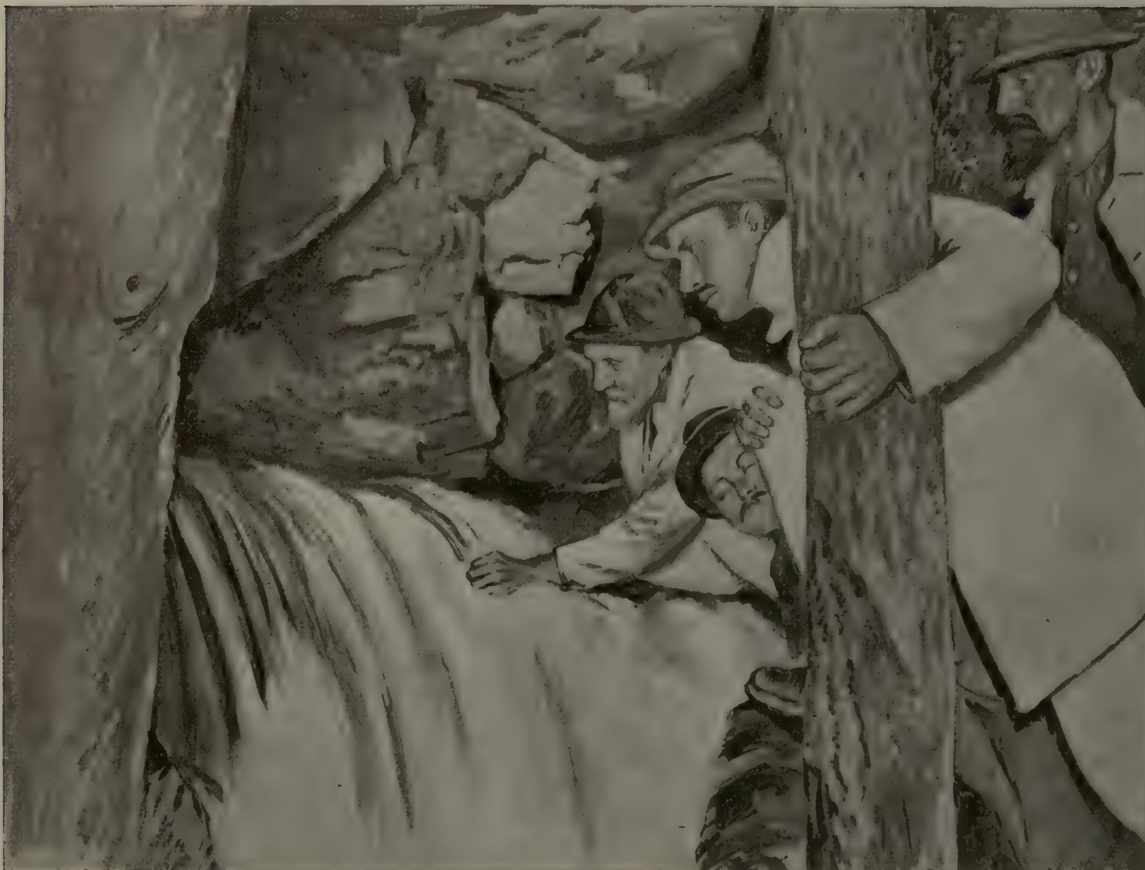
Twin Tunnels.

The gradients adopted were 1 in 500 on the Swiss, and 1 in 143 on the Italian side, these to be connected in the middle of the tunnel by a vertical curve of 10,000 metres radius and 80 metres long.

Under the contract, signed on April 15, 1898, the first tunnel was to be ready for traffic within five years and nine months from date, and the second four years later. Subsequently the period was extended by one year. Care for the workmen was shown in clauses specifying that the working faces should be kept moderately cool and be well ventilated, and that cheap and good lodging and food should be provided. These conditions were observed most loyally by the contractors.

Before boring operations began—on August 1, 1898—a most thorough survey of the pass and the surrounding peaks had been made, to determine the direction of the tunnel. At each end a sighting-point was fixed from which to project the centre-line through the tunnel. As the working advanced, sighting stations were added at points in the tunnel itself, at intervals of a mile or two miles, to carry the line forward. This part of the work was so accurate that the error in direction amounted

Surveying.



AN INROAD OF WATER, SIMPLON TUNNEL WORKS.

to but 8 inches in the $12\frac{1}{3}$ miles, and that of level to but $3\frac{1}{2}$ inches. The calculated length of the tunnel was within half an inch of the actual length!

Tunnelling.

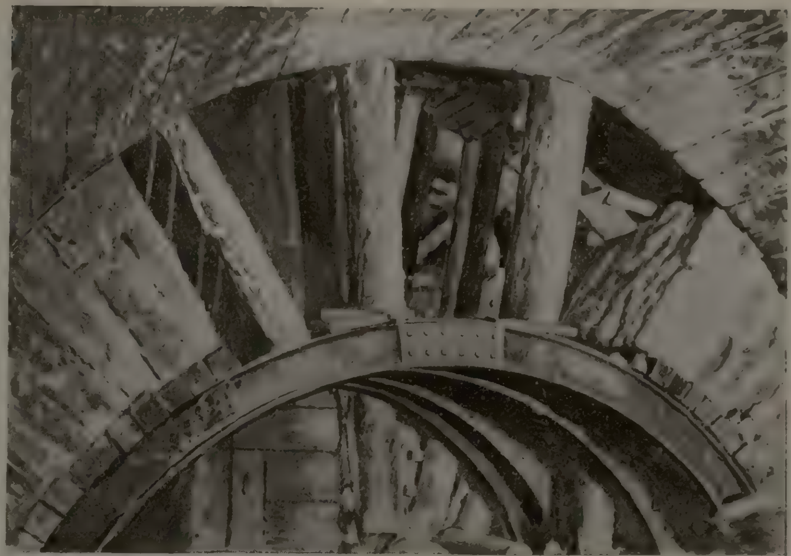
The tunnelling method adopted was to drive the two parallel tunnel headings simultaneously and "break up" from heading No. 1 to roof-level, drive top headings both ways, and gradually excavate to full size,* and timber the works in readiness for the masons following behind. The cross-passages between the two tunnels were closed, with the exception of that nearest the working face, so that the air forced by powerful centrifugal fans up heading No. 1 should return by heading No. 2 at the inmost point possible. To ensure, further, that the workmen should have plenty of fresh air to breathe, large tubes, 15 inches in diameter, were taken to the faces, and through them were directed fine jets of high-pressure water, which induced a powerful draught of air cooled by contact with the water. Also, water sprays were fixed at various points to distribute cold water across the passages and reduce the temperature of the rock.

Series of Operations.

A narrow-gauge railway led from the portals up each heading, to transport men, materials, and *débris*. The cycle of operations to be performed during every "lift," or advance, of the drills are normally as follows: — The drilling machine, carrying three drills, is brought up to the face, fixed tightly by means of a hydraulic ram pressing on the sides of

* After penetrating some distance, the contractors abandoned the top gallery system, and opened out the tunnel from the bottom heading. This gave better ventilation.

the heading, and set to work to bore from ten to twelve holes for the blasting charges. Two men attend to each drill, one regulating the motor, the other directing the tool and replacing it when worn. In about a couple of hours the holes have been driven to full depth. They are cleared out carefully, and the dynamite cartridges, fuses, and detonators are inserted. Meanwhile, the drills and all other objects liable to be damaged by flying fragments of rock have been removed outside the danger zone, and the bottom of the heading has been covered with a movable steel flooring to facilitate the shovelling up of the *débris*. Immediately after the explosion the face is deluged by jets of water to clear the air. A truck having been brought up, the men, armed with pick and shovel, clear away the broken rock, and examine the sides and roof carefully, detaching any loose fragments.



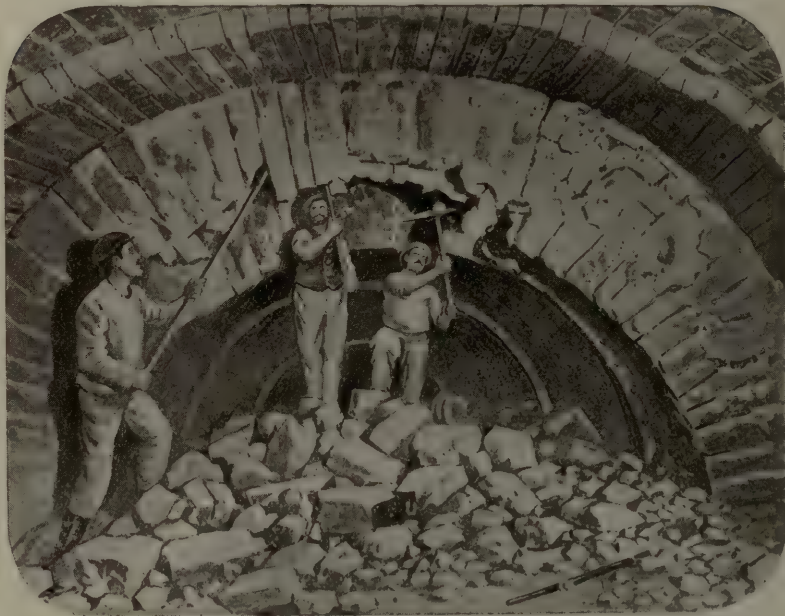
TIMBERING OF FALSE TEMPORARY ARCHES FOR SUPPORTING THE PERMANENT LINING AT DIFFICULT PLACES IN THE SIMPLON TUNNEL.

The time occupied by an advance—drilling, blasting, and clearing—occupied about five hours, allowing a daily advance of 18 feet. For haulage purposes, locomotives, driven by air compressed to over 1,000 lbs. to the square inch, were used in the headings. As the latter advanced it became necessary to make stations in the tunnel at which the supply of compressed air could be replenished.

The great average depth below the surface at which the tunnel was to be driven—the extreme being 7,000 feet under Mount Leone—promised very high temperatures and dangers from excessive pressure. The strata encountered were of gneiss, mica schist, and limestone. At many points water was struck, and squeezes, due to the horizontal direction of the strata, had to be counteracted by extra thick lining. The greatest troubles fell to the lot of the Italian workmen. At a distance of 4,400 odd kilometres (2·728 miles) from the Iselle entrance, the advanced gallery entered, in November 1901, very rotten ground, out of which cold water poured in enormous quantities at very high pressure, and drove back the miners. Simultaneously, the rock began to crush in the timbering. As soon as the flow had diminished sufficiently the miners proceeded to excavate by hand, and insert frames built of stout timber balks to protect the wagon way. These frames were, however, crushed like matchwood by the enormous pressure, and the heading closed. The engineers at once ordered frames of rolled steel beams having webs 16 inches deep and flanges 6 inches wide, to each side of which were bolted massive pitch pine balks 20 inches square. Even these could not resist the squeeze, and were seriously deformed, but by filling the spaces between the frames with quick-setting cement a secure path was formed for the advance beyond.

Difficulties encountered.

Though this troublesome portion had a



REMOVING FALSE ARCHES, SIMPLON TUNNEL.

length of but 40 metres, six months were consumed in driving the heading, and another year in getting in the lining. The cost came out at £1,000 for every yard run. This, however, is not surprising, in view of the fact that the tunnel had to be enlarged laboriously by hand to full section, and the space outside the frames then filled with temporary masonry, to give support for the timbering of the space subsequently excavated for the permanent lining, which was five feet thick.

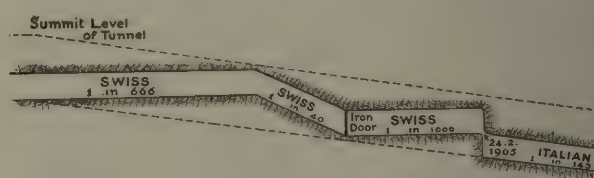
Costly Work.

This stage of the work, besides causing much serious delay, taxed the men severely. The stream of water mingling with the decomposed schist formed a slush in which the men were often sunk waist deep. To their credit be it said that such discomfort did not slacken their determination to overcome the immense difficulties with which they had to contend.

Meanwhile, in the Swiss portion of the tunnel excellent progress had been made, and the centre point was reached several months ahead of time.

Hot Springs struck on the Swiss Side—

In order to take full advantage of this, the headings were continued on a slightly rising gradient to the roof-level of the tunnel a short way down the Italian decline. Then the headings were given a downward slope of 1 in 40. Unfortunately, the rocks at this point were badly fissured, and discharged a quantity of hot water at such pressure as to detach and fling pieces of rock large enough to inflict serious injury on the miners. The heat of the workings became almost unbearable, although the rocks were deluged with cold water piped up the tunnel. Eventually a point was reached at which, owing to the depth of water accumulated, it became necessary to turn the headings upwards once more, on the very gentle gradient of 1 in 1,000. As a precaution iron doors were placed in both headings at the point



SKETCH SHOWING HOW HEADINGS WERE DRIVEN AT THE POINT OF MEETING IN THE MIDDLE OF THE SIMPLON TUNNEL.

The Italian party tapped the water accumulated in the southernmost Swiss heading on 24th February 1905, six and a half years after boring commenced at the entrances.

where the up-grade began, to be closed in case of an emergency. This proved to be a very wise step, for shortly afterwards an unusually hot spring was tapped, and, the cold water supply breaking down, the miners had to retire, making the doors fast behind them.

The situation now looked very serious in-

BRANDT DRILL AT WORK.

deed. It was freely asserted that the tunnel could not be finished. For the present all hopes were centred on the workers advancing slowly from the Italian side. They too struck a hot spring in gallery No. 1, which soon became untenantable. But gallery No. 2 fortunately ran through sound rock, and was pushed forwards until a cross-cut could be made to the line of No. 1, and that gallery be driven in both directions. Thus the hot spring was taken in the rear, and gallery No. 1 opened up.

And on the Italian Side.

The last serious obstacle had now been overcome. One Sunday morning the engineers in the northern part of the tunnel heard the drills of the Italian advance. By the middle of February 1905 only a few yards remained to be pierced; and on the 24th, at 6 a.m., the last blast was fired, releasing the hot water ponded up in the abandoned Swiss heading. The Italians had to retire with a haste which precluded the mutual congratulations usual on such an occasion.

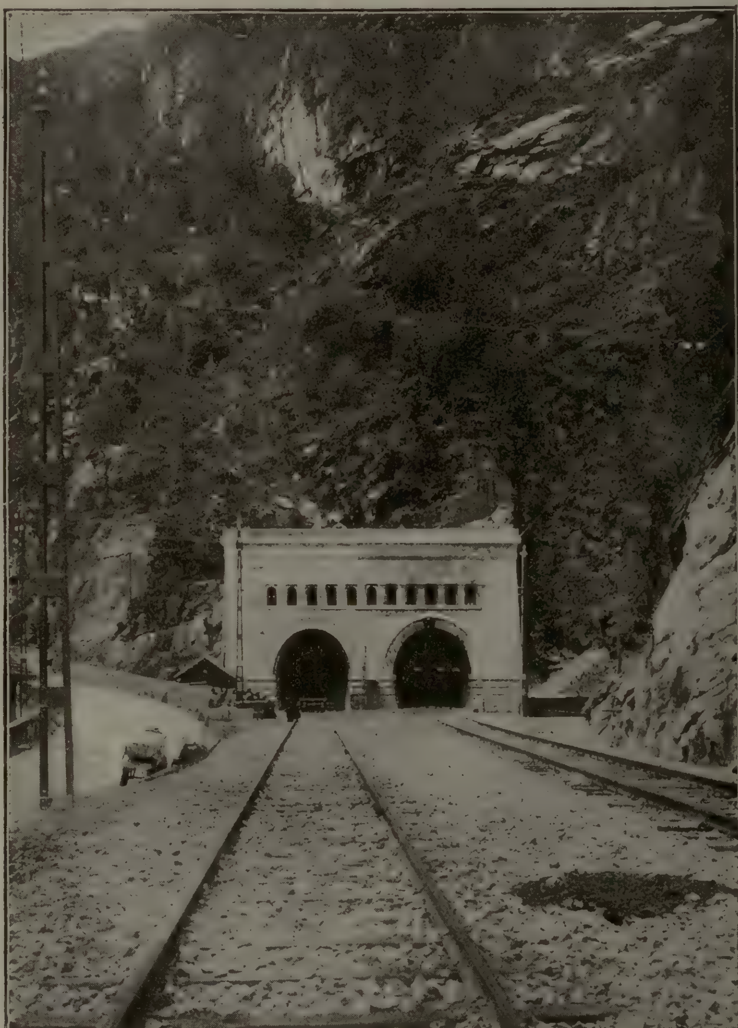
The Headings meet.

The last 245 metres of gallery had, on account of the hot springs, taken nearly six months to drive. But when through communication had once been established, there was no more delay. On January 25, 1906, the first train passed through the tunnel. Three months later the King of Italy travelled into Switzerland by the new route, and the President of the Swiss Republic returned with him on to Italian soil. One of the world's greatest engineering enterprises was concluded, and, by a curious coincidence, just a hundred years after the opening of the Simplon road, which also had been a wonder

The First Train passes through.

of its time. The driving of a long tunnel is, even under most favourable conditions, arduous work. Where it has to be prosecuted in the face of difficulties such as those met in the Simplon, the humblest workman becomes an unsung hero, and his chiefs the objects of general and well-deserved admiration.

When growth of traffic justifies the expense, gallery No. 2 will be enlarged to full section for a double track, which at present exists only for 500 yards in the mid-tunnel lay-bye, at which trains can pass one another. Meanwhile, it is useful in assisting ventilation, about which something may be added. The two portals, at Iselle and Brieg, are closed, except when a train is due, by thick canvas curtains and screens, sliding on an iron framework surrounding the entrance.



ISELLE PORTAL TO THE SIMPLON TUNNEL.
At present the right-hand entrance only is used for through traffic.
(Photo, Messrs. A. G. Brown, Boveri, and Company.)

Ventilation.

At the Brieg end two powerful centrifugal 10-foot fans drive air into the tunnel, from which it is exhausted by similar fans at the southern end. The curtains are raised by electricity or by hand.

Electric Locomotives.

For taking trains through the tunnel, powerful electric locomotives, which pick up current from duplicate conductors attached to the arch crown, are used. The locomotives have a weight of 62 tons, and develop a maximum of 2,300 horse-power. With a train of 300 tons they traverse the tunnel in eighteen minutes, at an average speed of 42 miles per hour.

The cost of the tunnel was about £3,200,000, or £148 per yard run. The work occupied 2,392 days, on each of which an average advance over the whole period of 13·69 feet was made at each face. On days when drilling machines were actually in operation, the average was 17·45 feet at each end, or 34·90 feet in all. This exceeded considerably the rate of progress in the Arlberg Tunnel. At the date of the meeting of the galleries, 3,740,000 holes had been drilled by hand and machine, 1,496 tons of dynamite exploded, and 1,229,500 cubic yards of rock exca-

TRAIN LEAVING THE SIMPLON TUNNEL AT THE BRIEG PORTAL. (*Photo, Locomotive Publishing Company.*)
ONE OF THE ELECTRIC LOCOMOTIVES USED FOR HAULING TRAINS THROUGH THE SIMPLON TUNNEL.
WEIGHT, 62 TONS; MAXIMUM HORSE-POWER, 2,300.
(*Photo, Messrs. A. G. Brown, Boveri, and Company.*)

vated.* The highest point above sea-level in the Simplon Tunnel is 2,313 feet, as compared with the 4,299 feet of the Arlberg, the 3,786 feet of the St. Gothard, and the 4,245 feet of the Mont Cenis tunnel. Thanks to this very moderate elevation, and to the absence of severe curves on the approaches, the run through the Alps is made at so good a speed that Milan has been brought within 25½ hours of London.

In connection with the new Simplon route another great project, the Loetschberg, is in hand. From Brieg a line will run parallel to the old railway to Lausanne for 11 miles, then turn northwards, plunge under the Loetschberg through an 8½-mile tunnel, and find its way down the Kander Valley to Frutigen, which already has railway communication through Thun and Berne with Germany and Northern France. It will therefore be a rival to both the Lausanne and the St. Gothard routes.

The Loetschberg Tunnel.

The tunnel, which has a maximum height above sea-level of 4,084 feet, was begun in October 1906, and, to fulfil the contract, must be completed by September 1911. It will accommodate two tracks. The approaches will include some very stiff gradients, especially on the Frutigen side, where there is a 9⅓-mile stretch of 2·7 per cent., and to obtain this much tunnelling and looping is required. The alternative of a longer, lower level tunnel was given due consideration, but abandoned on account of the decision to use electric haulage, which is more economical than steam on steep grades. It is anticipated that the extra power needed will not cost as much as the interest on the extra capital required for a low-level tunnel.

* *Proceedings of the Institute of Civil Engineers*, vol. clxviii.

Before closing this article we must refer to the tunnel through the High Tauern Alps, in the Austrian Tyrol. The completion of this tunnel in January 1909, and of the railway between Bad Gastein and Spittal on the Drave, has opened a route of international importance between Munich and Trieste, *viâ* Salzburg, Gastein, and Villach, and has shortened the journey from Salzburg to Trieste by 154 miles. The whole of the new track is remarkable for its engineering features, which include many viaducts and a number of tunnels, among which the Tauern is the most notable. This has a length of 5¼ miles, and was driven through a mountain composed of felspar, gneiss, quartz, and detonating shale. The last gets its name from its breaking off at the face with loud explosions when exposed to air. The hardness of some of the rocks, inroads of water, and the peculiar behaviour of the shale caused much trouble and delay; but all difficulties were overcome by the perseverance characteristic of the engineer, and the galleries met on July 12, 1907. The error in direction and level was extremely small.

The Tauern Tunnel.

NOTE.—*For the photographs of operations inside the Simplon Tunnel we are indebted to Mr. Francis Fox, M.Inst.C.E., and for help in their reproduction to Mr. W. L. Law and Mr. W. T. Perkins.*

HYDRAULIC SUCTION DREDGE, SHOWING CUTTERS RAISED.

TRANSPORTATION CANALS OF THE UNITED STATES.

BY I. M. PEACOCK.

"RIVERS are ungovernable things, especially in hilly countries. Canals are quiet and very manageable." So said Benjamin Franklin, and at this late date the American people agree. The question of inland waterways in the United States is again coming to the fore.

The Value of Inland Waterways.

This highly important factor in the interstate and international commercial growth of a country has suffered from alternate fits of interest and absolute neglect. The question of transportation by means of inland waterways—canals, natural and artificial—must now be definitely taken up by the National Government, if the country is to keep the pace set by the intense development of the farms, forests, mills, and mines.

At the present moment there are 2,120 miles of operated transportation canals in the United States. The majority of these canals are owned and worked by various States or Corporations, but there is only one state canal of great importance—the Erie Canal, which the people of the State of New York are improving and modernizing at a cost of $20,000,000. Most other canals are under private control, and will continue to be of no value until individual state interest grows strong under the impetus of national interest.

A comparison of the inland waterway traffic of the United States with that of her keen in-

dustrial and commercial rivals—England, Germany, and France—shows that the United States is lagging behind. But the nation as a whole is beginning to recognize the fact that well-developed inland waterways are necessary to ensure the economic future of the country, and to demand that canal possibilities be examined in the light of modern improvements, engineering and physical. Hence the renewed interest in what was not long since dubbed "a dead issue."

Railroads v. Canals.

Of course the railroads are acknowledged to be the arch-rivals of the canals as a mode of transportation, though the two should work together, one supplementing the other. A day of reckoning came, however, when the railroads flatly refused any further freight reductions or larger rebates, and continued their pernicious practice of underbidding the waterways and afterwards raising prices, thereby smothering canal prosperity, but giving rise to the present and prospective drastic reforms in canal development. "Why not go back to our faithful canals for the transportation and distribution of articles of bulk—such as coal, iron, lumber, etc.—leaving to the railroads the handling of the perishable and 'rush' items—such as foodstuffs, etc.?" suddenly became the general question.

George Washington, in his well-known capacity of organizer, investigated, surveyed, and backed the first canal propositions. The affairs of the first canal company, the Potomac, flourished under the master hand of its organizer, only to languish and die as soon as that hand was removed when Washington was made President of the United States in May 1787.

Present Developments.

Time was when canals "just grew" in a haphazard sort of way as necessary adjuncts to exploiting the natural resources of a section of the country. But now the most famous engineers of England, America, France, and Italy are being called upon to devise and make possible a connected route of inland waterways, regardless of the natural and physical aspect of the sections of the United States to be traversed.

The realization of this great dream presupposes complete reconciliation between railroad and canal interests, and an extension of both to meet the insistent demand of the times, so that the known quantities of natural resources may be distributed to trade centres. Internal trade and transportation in the United States greatly exceeds its foreign commerce. The majority of American commodities are articles of bulk, which, to be handled successfully, demand cheap transportation—canals—with facilities for shipping from producer to consumer, obviating the middleman's share in the profit.

For instance, from the vicinity about Lake Superior comes three-fourths of the iron ore mined in the United States, and the largest part of this ore is carried hundreds of miles to be smelted in Ohio, Pennsylvania, and New York. In the south, cotton, lumber, and fruit await the means of widespread and thorough distribution. On the Pacific coast, grain, flour, minerals, fruit, etc., demand facilities for exchange and barter. The possibilities for complete exchange and then exporting of surplus are too great to be ignored. Perfect commerce, foreign and domestic, would result. Versatility of climate, local conditions, and population demand extensive and continuous inland traffic by railroad and canal.

A Great Project.

Transportation canals generally are divided into two classes—canals built to improve river or land navigation, and canals built to connect separated waterways. The canalization of rivers in the United States is taking a prominent place in bringing about the above schemes. The pet project of the present century, however, is to connect great natural waterways by canals, thus forming an endless

chain of rivers, lakes, canals, and canalized rivers, until ocean traffic shall be possible from the most inland point.

It is planned to connect the Ohio River with Lake Erie, the Mississippi River with Lake Michigan, etc. The entire Mississippi Valley, the Gulf Coast, and the Atlantic coast can be made a continuous system by means of inland canals along the Atlantic and Gulf of Mexico coasts. For this purpose there are projected—a canal across the State of Florida to connect the Gulf of Mexico with the Atlantic coast, canals to connect Chesapeake Bay with the Carolina Sounds and the Delaware River with the Raritan, and a canal across Cape Cod. In this way the entire eastern half of the United States could be circumnavigated on sheltered waterways.

A handful of dauntless men are responsible for the present-day prosperity to which canals are an important adjunct. These men braved the stubborn opposition of a legion of "cautious" New Yorkers, and negotiated and planned, schemed, and finally accomplished canal transportation as a state and national asset. Whenever the name of the originator of the now famous Erie State Canal, De Witt Clinton, was mentioned, the multitude said, "In Clinton's big ditch would be buried the treasure of the state, to be watered by the tears of posterity." Now we may say, "In Clinton's big ditch was planted the treasure of the state, to be fostered by the prosperity of posterity." This "big ditch" is now one of the commercial and engineering wonders of the world. When it is completed, a new era in trade and traffic will begin.

A study of the canals by State divisions will doubtless give the true aspect of the canal question in the United States. First and foremost comes New York State.

Old Erie, New York State, or Erie Canal:

In 1724, when the enthusiastic Surveyor-General of the Colony of New York pictured the great possibilities of inland navigation, and when later, in 1777, another enthusiast, Gouverneur Morris, declared possible the union of the waters of the Great Lakes with those of the Hudson River and the Atlantic Ocean, the matter immediately became a political issue. At last, in October 1825, a voice rang out in challenge across the water of the first Erie Canal.

"Who comes there?"

"Your brothers from the west, on the waters of the Great Lakes."

"By what means have they been diverted so far from their natural course?"

"By the channel of the Grand Erie."

"By whose authority, and by whom, was a work of such magnitude accomplished?"

"By the authority and by the enterprise of the patriotic people of the State of New York."

These challenges and answers greeted the first canal boat, the *Seneca Chief*, midway on its trip down the first American venture in canal-building as a permanent means of transportation. All along the route, from Buffalo to Albany, the people greeted the boat with holiday expressions of good-will and congratulation. On November 4, 1825, the boat and its load of officials arrived in New York City to witness the spectacular "wedding of the waters" in fulfilment of the prophecy of Gouverneur Morris, who, unfortunately, did not live to see his dream come true. Two kegs of water from Lake Erie, and bottles of water from the Nile, the Ganges, the Indus, the Thames, the Seine, the Rhine, the Mississippi, the Columbia, the Orinoco, and the La Plata, were all ceremoniously mingled in the Atlantic, thereby typifying international commerce by means of canals.

For fifty years the Erie Canal in its present state wielded a despotic sceptre over the commerce and growth of the entire State. After a time, however, its vigilance and jealous guard over its transportation suprem-

DAM BEING BUILT AT VISCHER'S FERRY, ON THE NEW ERIE CANAL.
LOCK IN COURSE OF CONSTRUCTION AT WATERFORD, NEW ERIE CANAL.

SUCTION DREDGE "ONEIDA" WORKING; CUTTERS LOWERED.

The spoil passes out through the pipes at the stern.

acy waned through its very affluence; and it was not until the National Government had deepened the channel in the Lakes to 20 feet and the Hudson River to 12 feet, and the Canadian Government had begun preparations to increase its average canal depth from 12 to 20 feet from Chicago to Montreal, that the Erie Canal began to look to its laurels. Previously the "Erie" had been content with its 7 feet for boats drawing only 5 feet. The rude awakening, however, to the fact that competition was increasing on all sides and smothering the Erie Canal, marked the beginning of many interesting experiments in steam and electric propulsion, and in the construction of bridges, banks, boats, locks, slips, etc.

Wane of the Old Erie Canal.

Electric Towage.

The first scheme for electric propulsion on the Erie Canal was known as the Milligan, which consisted of a series of 14-foot posts along the bank of the tow-path, carrying two continuous rails, known as the east and west bound rails, about three feet apart. A tow-line was connected with the boat from a 20 horse-power motor running on the rails. Another scheme—the Lamb system—consisted of a line of poles along the bank supporting a stationary cableway on which electric motor carriages travelled, towing the attached boats.

The present style of canal locks is a simple device based on the original invention of that versatile Italian, Leonardo da Vinci—a sort of tank or chamber placed in a canal in such a manner that a vessel can be lifted from one level to another by simply closing the end gate and filling the tank. This plan, with slight deviations, has been used for upwards of four hundred years; but now, in the twentieth century, the method is to be changed radically.

Heretofore canal-builders have sought long, easy grades, down which the canal could climb easily, assisted by the interposition

A LUBECKER EXCAVATOR SCOOPING EARTH FROM THE PRISM OF THE NEW ERIE CANAL.

of many locks. Now, the longest possible *level* route will be chosen, and the descent —now made through many tedious locks— will be made, where possible, in a single abrupt drop, reducing greatly the number of locks, the time now required for lockage, and the personnel and equipment.

The application of the new principle will be exploited in the resuscitation of the Erie State Canal of New York, beginning at the town of Lockport, where there are now five old-style locks. These five locks will be replaced by a pair of the new-style pneumatic lifts, having an extreme lift of 62½ feet (trebling the highest lift now obtainable). The new device will cost $500,000 in itself, and will have a capacity six times greater than the old locks, which cost almost $700,000.

New Erie or New York State Barge Canal.

A pneumatic lock consists of two units. Each unit has an upper boat chamber, to the bottom of which is attached an inverted caisson. When submerged, this caisson forms a natural seal for the compressed air inside. The locks work in pairs, one rising when the other falls. They move up and down in steel guiding-frames, and may be built either side by side or end on to one another.

An immense tube, fitted with a valve, permits the air to pass quickly from one of the compressed-air compartments to the other. The flow of compressed air is constant, except when a vessel has been locked through and the valve is closed. An extra pressure of air against the elevated lock from beneath, assisted by anchors above, holds the elevated lock in place.

Meanwhile, the depressed caisson settles quietly into the lower level of the canal. A vessel is admitted to either or both locks, and as a vessel displaces only its own weight of water, the compressed air keeps the locks in balance when the gates are closed. Upon an additional quantity of water being let into the chamber of the elevated lock, that lock sinks, forcing the air in the caisson

beneath through the tube into the other caisson. The locks change position, and permit the gates to be opened and the vessel or vessels to be floated out.

A lock of this type is being constructed at another point on the Erie Canal—namely, at

END VIEW OF A SUCTION DREDGER.

Pipes for delivering the spoil on to the banks seen in the background.

Cohoes, New York—to take the place of a series of fourteen of the old-style locks, and will have power to lift eighty Mogul locomotives. It is said that five hundred of these heavy locomotives could be lifted by this device if need be.

A detailed inspection of the prosecution of the numerous contracts let for this great work would offer excellent object lessons to engineering sceptics. The various contractors engaged upon the work are assembling modern machinery most suited to the various plans of the work, instead of employing makeshift equipment to do work other than that for which it was intended. For instance, dry earth and rock excavations are handled by steam shovels; Page scraper buckets throw up levees and excavate prisms in earth sections; hard subaqueous rock is carried away by orange-peel buckets and dipper dredges; soft subaqueous material by hydraulic and ladder dredges; and so on.

Modern Canal Machinery.

Most of the materials encountered — varying from soft sand and clays of all kinds to cemented gravel—can be handled by the hydraulic dredge known as the "Geyser." These machines have cutters weighing 7,000 lbs. each, and are driven by a double 10 × 12-inch engine of 65 horse-power. They

THE EFFECTS OF THE LUBECKER EXCAVATOR.

can dig 18 feet below water-level, discharging material through 1,500 feet of 20-inch pipe to a height of 25 feet above water. The pump is connected to a triple expansion marine engine of 450 nominal and 550 overload horse-power.

"Geysers."

The swing bridges along the canal are operated in most cases by electricity.

Another interesting detail of the work now in progress is the pile-driving equipment.

The drivers are usually mounted on wheels with a 19-foot gauge, and upon the framework is another set of wheels placed transversely to the first, enabling the whole outfit to travel back and forth over the work, or permit the leads to travel in a transverse direction to cover a line of piles 20 feet or more long at every forward move of the driver. In an eight-hour day one hundred and eighteen 25-foot piles can be driven.

Pile-Driving.

The sand and gravel washing and screening plants are also of interest. These plants are located on the sides of hills, at the top of which are the sand and gravel pits. An orange-peel bucket loads the excavated material into dump-wagons, which haul it to a set of "grizzlies," which reject all stone over three inches, and drop the small stuff through chutes to a jaw-crusher below. From the crusher the stone falls into the boot of a bucket-elevator, which hoists it to the storage-bin. The sand and gravel coming into the grizzlies pass on to a rotary screen, in which a jet of water is made to travel in the direction opposite to the movements of the sand and gravel. The sand drops into a hopper, and a screw conveyor carries it under water to a bucket-elevator, which deposits it in the storage-bin. The gravel goes direct to the bin, and the rejections (stones over two and a half inches) go to the crusher.

Screening, Crushing, and Washing Plants.

The concrete-mixing plants are built by individual contractors for work under their respective contracts. An elevated storage-bin, a mixer, and storage space on either side for sand constitute the principal features of these plants, which are driven by electricity. The stone and sand are dropped into measuring-boxes, and the cement added, mixed, and discharged into buckets on flat cars.

Another important canal is the Sault Ste. Marie, forming the northernmost link in the chain of inland waterways. Between two of the Great Lakes, Superior and Huron, we find a district teeming with the bustle, energy, and goodwill of a healthy international commerce, and a canal once described by one of America's greatest statesmen as a "work beyond the remotest settlement in the United States, if not in the moon!"

Sault Ste. Marie Canal.

In 1836 Michigan was initiated into the mysteries of statehood. In 1837, the first governor in his first message to the first Legislature of that State urged the immediate construction of a canal to assist in distributing the natural resources of that section—copper, iron, fisheries, furs, pine, timber, and farm products. Yet, notwithstanding this *known* wealth, and the enlistment of neighbouring States in the canal petitions, Congress could not be persuaded to loosen the national purse-strings. It did, however, present the canal interests with a land grant of 750,000 acres. Meanwhile, commercial interests were chafing under the repression of the possible boundless traffic. So a contract was agreed upon, which provided that the contractors, in consideration of the 750,000 acres, should construct within two years the long-wished-for canal between the two lakes.

The canal was to have two consecutive locks, 350 feet long, 70 feet wide, and 13 feet deep. The width of the canal was to be 100 feet, and the calculated cost was $557,739. The actual cost of the first attempt, however, was $999,803.46.

In June 1853 work began, and on April 19, 1855, the first boat passed through the locks of the now famous St. Mary's Ship Canal. Twelve years later the immediate enlargement of the canal became necessary to meet the insistent demand of the outside world for a share in the mineral wealth lying in the vicinity of the canal.

Enlarging the Canal and Locks.

A "WHALEBACK" STEAMER ENTERING THE LOWER END OF THE POE LOCK ON THE ST. MARY'S FALLS CANAL, BETWEEN LAKES SUPERIOR AND HURON.

THE WEITZEL LOCK ON THE ST. MARY'S FALLS CANAL; HIGH WATER.

The boats had grown in size, and the locks were not capable of handling them. The canal was at that time under state control, and it soon became evident that for the full development of the interests involved the wisest move would be to transfer it to the General Government. The transfer was effected on June 9, 1881, since which time no tolls have been collected.

In 1870 the rapid increase in commerce and in the carrying capacity of the boats brought about the construction of the Weitzel Lock, which was completed in 1881.

The Weitzel and Poe Locks.

It is 500 feet long, 80 feet wide in the chamber, and has about 14 feet of water over the sills at low-water. The walls are of limestone, and contain 34,207 cubic yards of masonry. Water is admitted into the lock through culverts under the floor.

Increasing commerce made yet another lock necessary. So the Poe Lock, with a chamber 800 feet long and 100 feet wide, and a depth of about 19 feet at low-water, was built to reinforce the Weitzel.

These locks were confidently expected to handle the commerce of Lake Superior, but at times are congested to an exasperating degree. Boats have reached a size that renders the present lockage facilities almost useless. Many of them now have a capacity of 8,000 tons, and at the present time there are some thirty-two of these 8,000-ton boats plying on the Lakes. This adds 20 per cent., or 338,000 tons, for a single trip, to the

THE TWIN LOCKS, THE WEITZEL AND POE, ON THE ST. MARY'S FALLS CANAL.

carrying capacity of the fleet transporting ore from the vicinity of Lake Superior. It is estimated that the trips of these vessels through the locks number 25,000 a year.

These "twin" locks, the Poe and Weitzel, are named after two able generals detailed from the War Department to make recommendations and supervise plans to suit the unprecedented commercial growth—a task in which they were ably assisted by the eminent engineer, Alfred Noble.

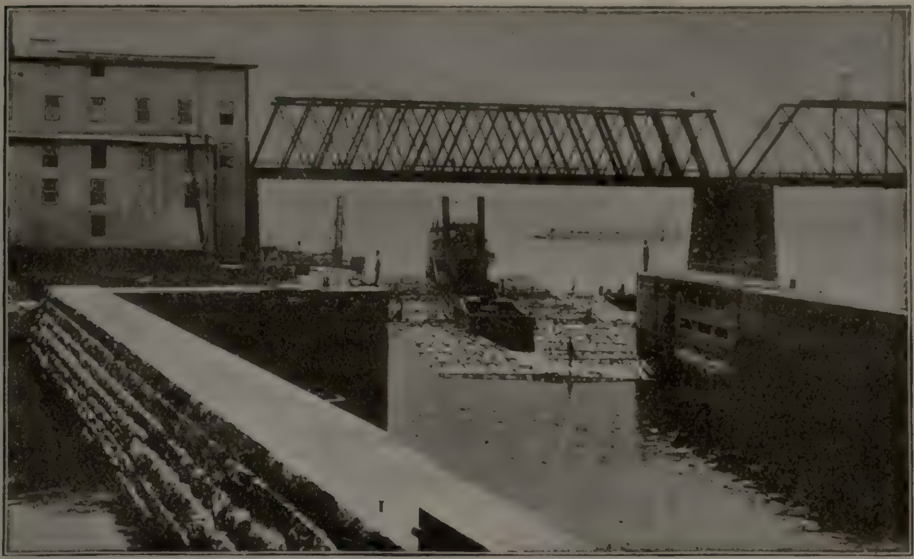
The appropriations made for the Sault Ste. Marie Canal and improvements total \$2,405,000. The length of the canal is 7,000 feet, and the least width—at the movable dam where the swing span or International Bridge is built—is 108 feet. The water averages about 16 feet in depth. Plans are now on foot by the United States Government to double the present width at the narrowest place, thereby relieving the present dangerous strong current that occurs when the locks are filled. This will also enable two or more locks to be filled at the same time.

This Sault Ste. Marie Canal is among the largest and finest engineering achievements in the United States, and will rank as first among its canals until the final completion of the Erie.

Traffic demanded a canal to connect Lake Michigan with the Mississippi River. Hence the Illinois and Michigan Canal, named after the State traversed and the lake in question.

Chicago Drainage Canal.

The first link in this is the Chicago Drainage Canal—or, as it is sometimes called, the Sanitary and Ship Canal—which cost about \$50,000,000. This canal can, if need be, carry the volume of a large river. Its use is twofold: first, as its name implies, it deals with the sewage of Chicago, a city of 2,500,000 persons; second, it is used largely for navigation between Lake Michigan and the Mississippi River. It is 34 miles long,



LOG RAFT, TUG, AND BARGE AT A LOCK ON A CANALIZED RIVER.

carry and dump earth and rock from the canal bottom to the spoil banks, hundreds of feet away, removing in a ten-hour shift an average of 500 cubic yards.

The canal was in some places cut a depth of 30 to 40 feet, through rock, with the aid of dynamite. Machines known as "channellers" cut 1½-inch crevices along the sides of the canal. In these, dynamite or gelatine was exploded, leaving a perfectly smooth vertical face.

The engineers also used ingenious dredges of huge proportions. A floating barge con-

26 feet deep, 300 feet wide on the surface. The sewage it carries is rendered innocuous by the immense flow of water. Formerly the sewage flowed into Lake Michigan through the Chicago River; but so many water supplies were polluted, and so much life endangered, that this canal was devised to cure the trouble, and also to make the city of Chicago queen of inland ports.

Wonderful modern machinery was used in the construction of the canal. Only two locks, of the new pneumatic type, will be required for its entire length. Immense bridge-like iron structures of the cantilever type, swinging like see-saws in mid-air,

A NEEDLE DAM, WITH NEEDLES REMOVED (ON THE RIGHT).
A barge is seen removing those of the left-hand portion.

taining immense pumps attached to a nozzle composed of a series of knife-like blades, places this nozzle on the spot to be excavated; the blades revolve, and the earth is drawn into a vast suction-pipe. A single dredge will move 168,000 cubic yards of earth in twenty-four hours.

The phases of the future water-power development on the Drainage Canal are interesting studies. A water-power plant at Lockport will have five units of 8,000 horsepower; and a large amount of water-power is now being developed at the south end of the canal, where it discharges through a tail-race into the Des Plaines River.

THE WOODEN NEEDLES OF A NEEDLE DAM, AND TRESTLE.

The controlling interests of the canal have been steadily acquiring from time to time strips of land from 200 to 800 feet in width, with a view to use in connection with manufacturing plants that will be installed to utilize the water-power to be developed, and to take advantage of the shipping facilities afforded, by the canal.

The Illinois and Michigan Canal.

The Illinois and Michigan Canal proper, of which the above described canal is only a unit, is 91 miles in length, with an additional 18 miles in the Illinois River. Its width averages 80 feet at water-line, and its depth is 7 feet. In all there are about thirty-four locks. Twenty have mitre gates throughout, and fourteen have lower gates of the mitre type, the upper, or "tumble," gates turning on a horizontal axis. Hydraulic pressure is used to lower the upper gates, which lift themselves by their own buoyancy. The locks are 35 feet wide and 170 feet long between mitre sills, and are built of concrete.

Proceeding down the Mississippi we reach cotton, lumber, fruit, and mineral districts. At the delta of this great river is found the interesting Lake Borgne Canal, in the State of Louisiana. It is 7 miles long, 200 feet wide, and very deep. Since 1901 it has given continuous water communication with three southern lakes (the Maurepas, Pontchartrain, and Borgne) and three southern rivers (the Mobile, Alabama, and Warrior). It has reduced distances greatly. Gulf of Mexico traffic is brought right up to the mouth of the Mississippi River, to the levees at New Orleans, Louisiana. Expensive transhipment has been abolished and freight-rates reduced. Sea-going vessels, drawing 10 and 12 feet, can come within 20 miles of New Orleans without the cost of towage.

This canal has also changed the status of coal in New Orleans. Prior to its construction, coal was a luxury, as it had to be floated 2,100 miles down the Mississippi River from Pennsylvania; but now Lake Borgne Canal has opened up the coalfields in the sister States of Mississippi and Alabama, reducing prices of

TRESTLES OF NEEDLE DAM LYING FLAT ON THE WEIR'S FOUNDATION SILL, SO THAT BOATS MAY PASS OVER THE SILL WHEN THE WATER RISES.

The trestles are lowered by being pulled over sideways. They are hinged top and bottom.

coal, and offering inducements to steamers purchasing bunker coal.

Passing eastward along the Gulf of Mexico coast, the next link will be a ship canal across the peninsula of Florida, connecting the Gulf of Mexico with the Atlantic Ocean, and obviating the long and tedious journey now necessary around the peninsula, through the dangerous Keys and Everglades.

The Proposed Florida Canal.

The next canal, the Albemarle and Chesapeake, on the coast of North Carolina, will, when improved to meet the new demands, do away altogether with the dangerous passage around Cape Hatteras of all vessels. The danger here from rocks, shoals, currents, etc., is evidenced by the long row of sentinel-like lightships stationed up and down the coast all the year round. The Dismal Swamp is partner to the above canal in handling the traffic to Norfolk, Virginia, the great trade centre and seaport of the south.

Albemarle and Chesapeake Canal.

Proceeding still further up the Atlantic sea-board, we come to the Chesapeake and Ohio Canal, 184 miles in length, with seventy-three old-style locks. The depth averages 6 feet. Steam propulsion varies with mule-towage as a means of transit.

Then, crossing Delaware to New Jersey, comes the Chesapeake and Delaware Canal, small but important, and awaiting modern improvements.

Now we diverge inland to the State of Pennsylvania, the great anthracite coal region. In this State canal history reads like a page from a romance. The discovery of anthracite coal brought about the construction of the Delaware and Hudson Canal in 1829, and afterwards, in rapid succession, of the Morris, Schuylkill, etc. These canals once carried approximately as much as 2,000,000 tons each per season, but have been practically killed by railroad competition.

The only canal of any importance in this State at the present day is the Pennsylvania Canal, 193 miles long, with seventy-one locks, and 6 feet deep. The present actual cost of moving freight on a 100-ton canal-barge is somewhat less than half a cent per ton per mile, and proportionally less according to size of the barge.

Moving westward, we come to the State of Ohio, wherein a healthy interest in canal affairs is evidenced by the efforts of the State

to adjust the question of boundaries between state and private canal lands, and to recover as many as possible of the state lands that are tied up by ninety-nine year leases and long-time rentals.

Ohio Canals.

This State, with its area of 40,760 square miles, its population of 4,157,545, and its natural resources of coal, iron, petroleum, and salt, is busying itself in the matter of canal traffic and the prosperity that follows in the wake of properly managed canal systems. It is purchasing its own machinery, dredges, drills, etc., and is replacing all the old wooden locks with staunch concrete structures.

The rivers in this State are being canalized to a remarkable degree, and the accompanying illustrations show the ingenious needle dams constructed to equalize the depth of the water during slack water seasons, and permit the utilization of the river by means of locks, even at low water, when the dams can be laid flat on the bottom of the river. The method of operation is simple but effective. The needles or pieces of timber are removed from their sockets and floated to the side of the stream; then, by jerking a chain—which is done by steam in a boat further up-stream—the dam collapses, unit by unit.

Movable Dams.

HALF OF A NAVIGABLE PASS.

A chain is attached at intervals to all the needles. When pulled it releases the needles from the frames, and allows them to float down-stream, as seen in the picture.

STEEL ARCH OF 150 FEET SPAN CARRYING THE PIPES OF THE ELAN-BIRMINGHAM AQUEDUCT ACROSS THE SEVERN.

(Photo, by courtesy of Messrs. J. Mansergh and Sons.)

GREAT BRITISH DAMS AND AQUEDUCTS.

BY THE EDITOR.

THE concentration of human beings into densely-populated areas, the consequent fouling of local surface water supplies, and the exhaustion or insufficiency of deep wells, give rise to the very serious problem of how to supply huge cities with a copious supply of wholesome water. The Romans faced the problem many centuries ago, and solved it by leading water from distant and unpolluted sources through masonry ducts, the remains of which are sufficient proof of the genius of the constructors. Roman engineers had so to plan and build their aqueducts that the surface of the water should follow the hydraulic gradient—an imaginary line joining the point of entry of the supply and the point of its ultimate discharge. Their aqueducts were, in fact, artificial rivers, which had to be carried on arches or walls across valleys and places where the natural surface of the ground fell below the hydraulic gradient. In order to avoid tunnelling—a very difficult matter to the ancients—hills had to be skirted, the length of the aqueduct increased, and the gradient flattened, which in turn involved the enlargement of the cross sectional area of the channel.

Roman Aqueducts.

THE SITE OF THE LAKE VYRNWY BEFORE THE WATER WAS IMPOUNDED.

A VIEW TAKEN FROM THE SAME POINT AS THE ABOVE, SHOWING THE GREAT DAM AND THE LAKE IT IMPOUNDS. On the right is the tower through which water is admitted to the aqueduct.

(Photos, J. Maclardy.)

The modern engineer enjoys the immense advantages conferred by the employment of iron and steel pipes able to withstand very high pressures, and the ability to drive long tunnels at a sufficiently low cost to make it worth while to substitute them for circuitous surface sections. He lays out his aqueduct on the shortest possible line between its ends consistent with economical construction; and it should be pointed out that shortness increases the steepness of the gradient, that steepness promotes velocity of flow, and that the faster water moves the smaller and cheaper is the pipe or channel which will convey a given quantity in a given time.

Modern Aqueducts.

According to the physical features of the country passed through, the most suitable of three methods of construction is selected. Where a hill is encountered and a detour is inadvisable, a tunnel is driven through it on the hydraulic gradient, and, where necessary, lined with cement or brick to prevent erosion of the rock and obstruction of the channel.

On sections where the surface of the ground follows the hydraulic gradient closely, cut-and-cover becomes practicable. This form of construction consists of digging a trench, building on the bottom an inverted arch (sometimes a flat floor is used), raising the side walls upward from this, and covering over the channel thus formed with an arched roof, on which some of the material excavated is placed to restore the natural level of the surface. At intervals manholes are fixed to give access to the conduit.

Three Methods of Construction.

Through undulating country and across valleys pipes are used. An unbroken length of pipe with its ends on the hydraulic gradient and intermediate parts below the gradient, is known as an inverted syphon, or, more shortly, as a syphon.

To prevent the pipes being subjected to an excessive "head" of water, open "balancing reservoirs" are, where necessary, and where physical conditions permit, built on the hydraulic gradient. Into each of these water is discharged from the lower end of the syphon immediately above, to be passed into the upper end of the syphon immediately below. The reservoirs also serve for local supply service, and assist in the regulation of the flow through the aqueduct.

Balancing Reservoirs.

The hydraulic gradient of both tunnel and syphon sections is in many cases made steeper than the general gradient, as these two classes of construction are more costly than the cut-and-cover or conduit, and because, as has already been pointed out, steepness allows reduction in the size of the channel.

Tunnels and conduits are made full size in the first instance—that is, are given a cross section of sufficient area to pass the full supply for which the aqueduct is designed. In syphon sections the flow is distributed among a number of separate pipe lines, which are laid successively as the need for an increased supply arises.

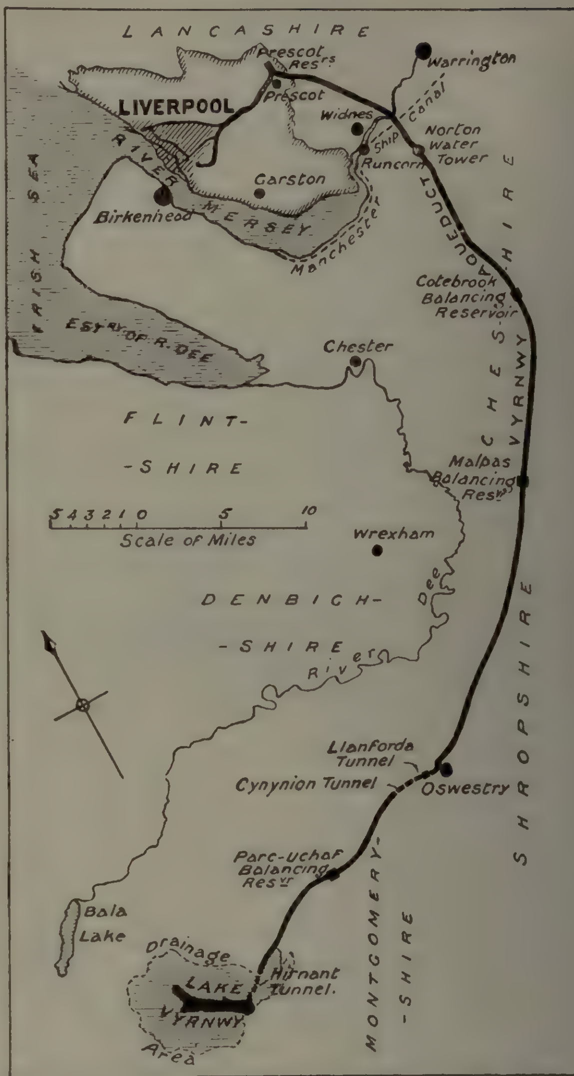
From these preliminary remarks we proceed to a description of some of the most notable British aqueducts.* The first chronologically is that which leads water to Glasgow from a series of lochs—Katrine, Drunkie, and Vennachar. Across the mouths of the first and last of these lochs were built masonry dams; the level of the second was raised by means of earthen embankments. From the lochs the water passes through an aqueduct 25¾ miles long to the Mugdock reservoir, where it is strained for delivery to the city. Of its length, 13 miles consist of tunnels, driven mostly through sound hard rock; 9 miles of cut-and-cover; and 3¾ miles of syphon, made up of two lines of 48-inch pipes—one only

The Glasgow Aqueducts.

* Lack of space prevents a description of the Dublin and Edinburgh aqueducts.

was laid in the first instance—and one line of 36-inch pipes. This aqueduct, which passes 40,000,000 gallons a day, was commenced in 1855, and opened in 1859. Its ruling gradient is 10 inches in the mile.

The Glasgow water supply was increased subsequently by a new aqueduct, which follows much the same course as the old, but has a daily capacity greater by about 20,000,000 gallons.



SKETCH MAP SHOWING THE COURSE OF THE LIVERPOOL AQUEDUCT.

Tunnels are indicated by broken lines.

The Vyrnwy-Liverpool Scheme.

A more ambitious scheme than that described thus briefly was one set on foot in the late 'seventies by the Corporation of Liverpool for supplying that great city with water from either the Lake District of Cumberland or from the valleys of North Wales. It was decided to impound the Vyrnwy, a tributary of the Severn, in Rad orshire, by means of a masonry dam, and conduct the waters of the reservoir so formed through an aqueduct 68½ miles long to reservoirs at Prescot, 8½ miles east of the Liverpool Town Hall. During 1879 the late Mr. G. F. Deacon, M.Inst.C.E., the engineer in charge of the works, completed the surveys and prepared the Parliamentary plans. In 1880 the Act conferring the necessary powers received the Royal Assent, and in the following year operations commenced.

The Vyrnwy Dam.

A site for the great masonry dam impounding Lake Vyrnwy, which at high-water level contains more than 12,000,000,000 gallons, was selected at the crest of a natural dam formed across the bed of the valley by glacial action at some far distant period. The dam is 1,172 feet long at the crest, 161 feet high above the lowest point in the foundations, and 127 feet thick (maximum) at the base. It contains 260,000 cubic yards of masonry, and weighs 679,000 tons. Across the top runs a fine carriage-way on arches, through nineteen of which passes all surplus water in times of heavy rain, and falls in an almost unbroken sheet down the face of the dam into the valley below. To ensure a secure foundation the bed had to be trenched to firm rock, and during this process huge masses of rock, weighing in some cases hundreds of tons, were blasted and removed. The interior rubble work and the facings of rectangular stones were built up with the greatest possible care round large discharge culverts. At each end the masonry is tied into the native rock.

The Water Tower.

Water enters the aqueduct at an ornamental tower, 170 feet high, which rises 100 feet above high-water level at a point in the lake about three-quarters of a mile from the dam. Outside the tower are two sets of six vertical tubes, and inside two sets of four similar vertical tubes, each 9 feet long, placed end to end and moving in guides. At the bottom the sets are connected by a pipe. Water can be admitted at any joint by raising the pipes above, a system which enables the supply to be drawn from near the surface, where the water is purest, whatever be the level of the lake. Within the tower the water is strained through wire gauze having 10,000 meshes to the square inch, and then passes through valves into a concrete culvert leading to the Hirnant tunnel, with which begins the aqueduct proper.

THE WATER TOWER AT LAKE VYRNWY. *(Photo, J. Maclardy.)*

It rises 60 feet above high-water level, and has a total height of 170 feet.

The Aqueduct.

The aqueduct is made up entirely of tunnel and syphon sections. The tunnels, which have an aggregate length of only about 3¾ miles, are designed to carry at least 40,000,000 gallons a day. Two lines of 42-inch pipes have been laid, and a third will be added when required. On the hydraulic gradient are five balancing reservoirs—at Parc Uchaf (9⅝ miles from the lake), Oswestry (18 miles), Malpas (36½ miles), Cotebrook (48 miles), and Norton (59 miles). The Oswestry reservoir is formed by an earthen embankment, able to impound 46,000,000 odd gallons. Beyond the reservoir are filter beds and a clean water reservoir, through which the water passes on its way to the next syphon. Between the Cotebrook and the Prescot reservoirs, a distance of 20 miles, the ground nowhere reaches the hydraulic gradient. At Norton Hill, about midway, it was decided to construct a reservoir. As the surface lay 110 feet below the gradient, a handsome tower of red sandstone was built to the required level. It supports an enormous circular tank, 80 feet in diameter and 31 feet deep at the centre. The basin-shaped steel bottom has a depth of 21½ feet, the upper cast-iron portion a height of 10½ feet. The weight of the tank and its contents (650,000 gallons) is borne by rollers resting on a cast-iron bed-plate supported by the coping of the tower. This arrangement allows for the expansive and contractive movements of the metal.

INLET END OF TUNNEL AT CRAIG GOCH DAM. (*Photo, by courtesy of Messrs. J. Mansergh and Sons.*)

The longest tunnel on the route is the Hirnant, at the lake end. This is 3,900 yards long, has a circular section with a minimum diameter of 7 feet, and falls rather more than 2 feet in the mile. The Cynynion tunnel (1,520 yards) and Llanforda tunnel (1,640 yards) are separated only by a short 183-foot syphon.

Tunnelling under the Mersey.

The driving of the fourth and last tunnel, that carrying the pipes under the Mersey, provided the greatest of the difficulties with which the engineers had to contend. This tunnel, which, as Mr. Deacon has pointed out, was the first ever constructed by means of a shield and compressed air under a tidal or other river through entirely loose materials, is lined with cast-iron segments bolted together. A shaft was sunk in each bank of the river, and the tunnel driven and lined for 57 feet at the Cheshire end. The first contractors then retired. Their successors commenced a fresh tunnel at a rather higher level, and succeeded in driving it for 61 yards. Then they too were defeated by the looseness of the river bed and the frequent inroads of water. Finally, Mr. Deacon took the matter in hand, repaired the shield, and completed the tunnel in four and a half months, so placing to his credit a memorable achievement. The tunnel has an inside diameter of 10 feet, and can accommodate three lines of 32-inch pipes.

Temporary Connection across the Mersey.

As the difficulties at the Mersey caused serious delay in delivering the Vyrnwy water to the Liverpool reservoirs, it was decided to effect a temporary connection while the tunnel was being completed. Mr. Deacon therefore had made a

number of 12-inch steel pipes furnished with flexible joints, and having valves at one point in the circumference. An 800-foot length of this piping was fitted together on sliding ways in a trench on the Lancashire side of the river. Both ends were plugged to exclude water.

When all was ready, steam winches on the Cheshire side, hauling on steel cables attached to the near end, drew the pipe off the ways and across the river. Within an hour of the start the plugs had been withdrawn, connections had been made with the pipe line at both ends, and water was flowing through the pipes. Then the Lancashire end was plugged to allow the water to issue at high pressure through the valves—the pipes had been so arranged that this should be at the lowest side—and scour a trench for the pipes in a bank of sand and silt at mid-stream. This ingenious method of trenching proved very successful.

The area of Lake Vyrnwy is 1,121 acres. Tunnels now connect the reservoir with the Marchnant and Cowny Rivers, forming gathering grounds of 27,000 acres extent.

In 1892, almost exactly eleven years after the laying of the memorial stone on which is recorded the commencement of the works, the undertaking was declared open by the Duke of Connaught.

The Thirlmere-Manchester Scheme.

Prior to the opening of the Thirlmere Aqueduct in 1894, Manchester depended entirely for its water on the supply—25,000,000 gallons a day—drawn from the river Etherow, at Longdendale, 18 miles east of the city.

As early as 1875 it became evident that measures must be taken for tapping some other source, in order to prevent the demand overtaking the supply. The Corporation decided to obtain water from Thirlmere, one of the Cumberland lakes, into which drains an area subject to a very high annual rainfall. The surface of the watershed being free from peat, the water that flows off is well suited for human use. An Act of Parliament was obtained in 1879, authorizing the construction of a dam across the northern end of the lake to create a reservoir that should supply Manchester with a maximum of 50,000,000 gallons a day for 160 days without replenishment by rain, and the construction of an aqueduct able to pass this amount of water.

The dam, which was begun in 1890, is 857 feet long at the top, and has a greatest height above the foundation of 104 feet 6 inches. At present it increases the depth of the lake by a maximum of 35 feet, but if raised to its full projected height, will add another 15 feet, and produce a storage capacity of 8,135,000,000 gallons.

A small hill divides the dam into two portions. Through this hill was driven a tunnel for the discharge of surplus and compensation water. No water passes over the dam itself. It may be added that the area of the lake has been increased from 330 to 690 acres by the creation of the dam, and that, as a consequence of the rise of water level, an entirely new coach road has had to be built along the west bank of the lake, in addition to a road along the crest of the dam to connect the two sides of the valley.

The Thirlmere Aqueduct.

The aqueduct is made up of 13 miles 1,517 yards of tunnel, 37 miles 120 yards of cut-and-cover—all for 50,000,000 gallons a day—and 45 miles of syphons. For the two syphons nearest the lake three lines of 48-inch pipes are specified, and for the other syphons five lines of 40-inch piping, except in the part of the aqueduct south of Little Hulton, where the gradient is steeper, and 36-inch pipes are able to deal with the flow.

Aqueduct pipes are generally of cast iron. Where exceptionally high pressures have to be borne—as at the lowest point of a deep syphon

CUT-AND-COVER CONSTRUCTION IN PROGRESS, ELAN-BIRMINGHAM AQUEDUCT.
The bottom and part of the side walls have been built.

LOWERING A 42-INCH PIPE INTO TRENCH, RIVER WYE SYPHON.

(Photos, by courtesy of Messrs. J. Mansergh and Sons.)

—or the pipe is of unusually large diameter, steel is used. According to the duty which it may have to do, a 48-inch cast pipe—about the limit diameter for this type—varies in thickness from 1 inch to $1\frac{3}{4}$ inches. A pipe is cast socket end downwards, so that the densest metal may be at the part liable to fracture during the caulking of the lead at the joint. Bars are cast at the same time as a pipe and numbered similarly, and subjected to certain standard weight tests. If the bars do not come up to requirements, the pipe to which they refer is rejected. If the pipe passes this test, and also those for dimension, uniformity of thickness, ability to withstand a pressure considerably greater than it will have to bear in the aqueduct, soundness (made by inspection and by rapping it with a hammer), and weight, it is heated and dipped bodily into an anti-corrosive preparation. When this coating has dried, the pipe is ready for laying. Full records are kept of every pipe for reference purposes.

Cast-iron Pipes.

The commonest form of cast pipe has a socket at one end and a spigot at the other. A spigot has an external diameter somewhat smaller than the internal diameter of a socket, so that when a spigot is inserted into the socket of the next pipe an annular space shall be left between the two for yarn packing and for lead, which is run in, allowed to cool, and caulked, or compressed, with a special tool. The socket is recessed inside so that the lead may resist any force tending to draw the two

Making the Joints.

CULVERT IN THE CAREG-DDU SUBMERGED DAM, ELAN RIVER; DOWNSTREAM FACE.

(Photo, by courtesy of Messrs. J. Mansergh and Sons.)

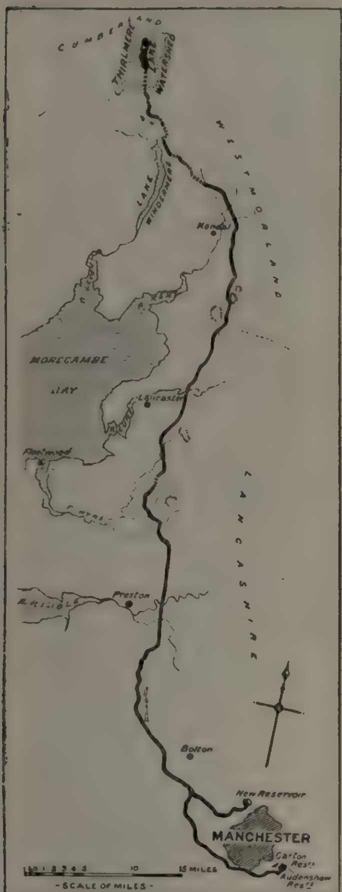
THE HUGE STEEL PIPE, $8\frac{1}{2}$ FEET IN DIAMETER, FOR THE BIRMINGHAM AQUEDUCT AT MAES-Y-GELLI.

This pipe is able to pass the full quantity for which the aqueduct is designed, 75,000,000 gallons a day.

THREE PIPES IN TRENCH, HOPTON BROOK SYPHON, ELAN-BIRMINGHAM AQUEDUCT.

The left-hand pipe is an overflow pipe.

(Photos, by courtesy of Messrs. J. Mansergh and Sons.)



SKETCH MAP SHOWING COURSE OF THE THIRLMERE - MANCHESTER AQUEDUCT.

pipes apart. In some cases a wrought - iron ring is shrunk over the socket to assist in preventing fracture during caulking. In moderately flat country cylindrical socketless pipes, joined by collars embracing the adjacent ends of two pipes, are used. For negotiating horizontal or vertical angles and curves special angle castings become necessary. On severe slopes pipes must be anchored to prevent downhill movement, and be duly supported on the outside of curves against outward thrust. In this country it is customary to cover water-pipes with at least 2½ feet of earth as protection against that arch-enemy of the hydraulic engineer, Jack Frost.

Automatic Valves.

However carefully a syphon may be designed and laid, there is always the possibility of a burst occurring in it. Were such a vast volume of water as is carried by a large aqueduct allowed to escape unchecked, the results, apart from the great waste, might be disastrous. A syphon is therefore furnished with a number of valves, under the control of the walksmen who patrol the line, whereby an outburst may be restrained. A further safeguard is provided by valves which automatically cut off the supply in the event of a rupture. In a paper read before the Institution of Civil Engineers, Mr. G. H. Hill, M.Inst.C.E., describes the mechanisms of this class which protect the Thirlmere Aqueduct.

At the north—that is, the upper—end of each syphon is a chamber divided transversely by a wall. The southern part of the chamber is subdivided by partitions into a number of float wells, one for each of the pipe lines of which the syphon will ultimately be made up. The north compartment has communication with each float chamber through a pipe, the ends of which are turned up so that the lips are horizontal. Over the northern orifice of the pipe a bell-shaped vessel, open end downwards, is suspended from a lever 18 feet long pivoted at the northern end, and carrying at the other a large metal float. Should a burst occur in the syphon pipe the water in the corresponding float well sinks, and allows the bell in the northern chamber to seat itself over the entrance to the communication pipe, and so cut off the supply. Any excess of water from the aqueduct is discharged through a channel at a level below the top of the cross wall.

Automatic Throttle Valve.

Another type of automatic valve is fitted at intermediate points in the northern legs of the longer syphons. A disc valve, which, when turned into a vertical position, seals the waterway, is carried on trunnions projecting through stuffing boxes in the sides of the valve box. On the ends of the trunnions are pulleys, to which heavy weights are attached by chains. Under ordinary conditions the valve lies in a horizontal position, allowing the water to pass at its normal velocity.

Upstream of the valve a circular plate, on the end of a rod pivoted in an air chamber above the valve box, projects into the waterway. Should a burst occur, the increased velocity and pressure of the water causes this

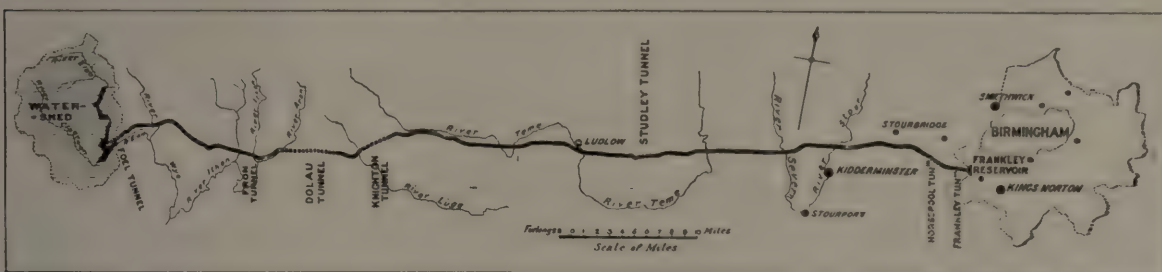
THE CABAN COCH DAM ON THE RIVER ELAN. SURPLUS WATER FLOWING OVER WEIR AT THE CREST. (*Photo, F. Milner.*)

The dam is 560 feet long and 122 feet high.

plate to move and release a trigger. The weights rotate the pulley at a speed governed by a hydraulic cataract, and bring the disc valve slowly into a vertical position, checking the flow of water.

The third class of automatic valves to be noticed are those in the southern legs of the syphons. These valves have doors which open only in the direction of normal flow, and close against their seatings if a rupture causes the water to flow backwards toward the lowest part of the syphon.

The scheme, originated and carried out by the late Mr. James Mansergh, Past President Inst.C.E., for which Parliamentary powers were obtained in 1892—with supplements at later dates—included the construction of a dam on the Elan below the confluence of the two streams, of two more higher up the Elan Valley, and three in the Claerwen Valley, to impound six reservoirs forming two flights of gigantic water stairs up the valleys in question. The watershed acquired has an area of over 70 square miles, and an average annual



SKETCH MAP SHOWING ROUTE OF ELAN-BIRMINGHAM AQUEDUCT.

At the present time two pipe lines, conveying 20,000,000 gallons a day from Thirlmere to Manchester, have been completed, and arrangements are in progress for laying a third line. The scheme was prepared by the late Mr. J. F. Latrobe Bateman, F.R.S. (the engineer of the Longdendale works), in connection with Mr. G. H. Hill, who carried it out on behalf of the Corporation. The cost of the watershed and lake, of all necessary way-leaves, of the construction of tunnel and cut-and-cover sections, and of two pipe lines, amounted to about £3,500,000. It is estimated that the total cost of the completed scheme will be £5,000,000.

The Birmingham Aqueduct.

The next great British aqueduct to be noticed is that commenced in 1893 and opened in 1904, which brings water 73 miles from the Elan and Claerwen valleys, in Wales, to Birmingham. The two rivers named are tributaries of the Wye.

rainfall of $61\frac{1}{3}$ inches. At 36 inches per annum the fall would yield about 100,000,000 gallons a day—more than ample to meet all requirements.

At the time of writing, all the dams in the Elan Valley have been completed, and the foundations laid for one in the Claerwen.

The Caban Coch Dam.

The lowest of the dams, the Caban Coch, is 566 feet long at the top, 122 feet above the river bed, and $122\frac{1}{2}$ feet thick at the base. It impounds 8,000,000,000 gallons of water, and forms a lake which extends some distance up both valleys. Below the dam is a power-station, wherein the compensation water let out into the river is utilized to generate electricity for use on the filter beds and for lighting purposes, and to operate a hydraulic accumulator for working the valves at the dam and at the inlet to the aqueduct.

One and a half miles farther up the valley is a submerged dam—not referred to previously—which rises to an elevation 40 feet

below high-water level. This dam divides the contents of the reservoir into three portions:

A Submerged Dam.

a top slice, 40 feet thick, covering the whole area of the reservoir, and available for compensation water or for withdrawal through the aqueduct; the water below a horizontal line drawn from the crest of the submerged dam to the Caban Coch, for compensation purposes only; and that impounded by the submerged dam independently of the Caban Coch. The aqueduct, it should be mentioned, has its intake immediately above this dam.

The next of the series, the Pen-y-Gareg, is 123 feet high, and creates a reservoir of 1,320,000,000 gallons; the third, the Craig Goch, is 120 feet high, and impounds 2,000,000,000 gallons. When the other three dams have been built the total

Pen-y-Gareg and Craig Goch Dams.

storage capacity of the system will total 17,960,000,000 gallons, or about one and a half times the quantity of water impounded in Lake Vyrnwy. All surplus water passes over the crests of the dams, forming in flood seasons a series of magnificent waterfalls, set in most beautiful surroundings.

The reservoirs cover the sites of two houses associated with the poet Shelley, a church, a chapel, a school, and a number of cottages. All of these buildings were demolished, and most of them replaced by new structures on

PEN-Y-GAREG DAM, ON THE ELAN RIVER. LENGTH, 417½ FEET; HEIGHT, 123 FEET. (*Photo, F. Milner.*)

higher ground. In this connection we may note that Lake Vyrnwy covers the site of the village of Llanwddyn, with its church, school, three chapels, and forty cottages.

The Aqueduct.

The aqueduct consists of 23⅞ miles of cut-and-cover in nineteen sections, 12¾ miles of tunnel, and about 36¾ miles of syphon. Tunnels and cut-and-cover conduits have a normal internal section 8 feet high, 98 inches wide at the springing of the arch, and 86 inches wide at the invert. They are lined throughout with blue brick, and are able to pass a maximum of 75,000,000 gallons a day. The syphons will ultimately have six lines of 42-inch pipes; at present only two lines have been laid. The total fall on the 73 miles is 169 feet, or about 2⅔ feet to the mile. The gradient of the syphons ranges between 1 in 1,760 feet and 1 in 1,570 feet. To some readers it may be a matter for surprise that so very gentle a slope should suffice for an aqueduct which has to deliver huge quantities of water through comparatively restricted channels.

On leaving the lake the water passes through the Foel tunnel to the Elan filter beds, where it is strained and purified. The next 15 miles are in cut-and-cover, interrupted by four short syphons and two short tunnels. Near Dolau it enters a tunnel 4¼ miles long. Emerging from this, it traverses 2 miles of conduit, a short syphon, and the 2¼-mile Knighton tunnel. A mile of conduit is succeeded by the Downton syphon, 9½ miles long, which at two intermediate points rises to the hydraulic gradient, and twice crosses the river Teme. The next 4 miles are mostly in cut-and-cover. Then comes the big Teme syphon, 4¾ miles long, with a greatest hydraulic head of 444 feet, and a series of short conduit and tunnel sections leading to the Severn syphon, which covers 17½ miles. At the point where they cross the river Severn, over a fine arch bridge of 150 feet span, the pipes are subjected to a hydraulic head of 540 feet, the greatest on any British aqueduct. From the Birmingham end of the syphon the water is led to the Frankley reservoirs and filter beds through 5¼ miles of conduit syphon and tunnel. The receiving reservoir is semicircular in plan, has an area of 25 acres, and holds 200,000,000 gallons.

Derwent Valley Waterworks.

The Derwent Valley waterworks are of particular interest, as the first great scheme for affording a supply to a combination of large towns. The cities of Leicester, Derby, Sheffield, and Nottingham all wanted water from the watershed of the Derwent. In the autumn of 1898 the first three deposited separate plans, and applied for Parliamentary powers to carry them out. Nottingham, and the counties of Nottingham and Derby, also petitioned for a share of the water. The Parliamentary Committee appointed to investigate the matter decided that all the parties concerned should unite to carry out works to obtain a supply divisible among the claimants in certain proportions; and powers were granted for creating six reservoirs in three instalments in the valley of the Derwent. The first instalment, the Howden and Derwent reservoirs, was taken in hand in 1900. As a preliminary to building the dams, a railway seven miles long was constructed through difficult country from Bamford, on the Midland Railway, to the site of the Howden dam, where a village was built to accommodate the workmen and their children. The Derwent dam has a length of 1,110 feet at the water-line, rises 114 feet above the bed of the stream, and is 169 feet thick at the widest part of the foundations.

A Huge Dam.

The masonry of the dam measures 360,000 cubic yards, and is computed to weigh 630,000 tons. As the rock leaked at the level of the foundations, the engineers had a trench 6 feet wide cut down into the rock and filled with masonry to form an imperme-

THREE PIPE LINES OF THE BIRMINGHAM AQUEDUCT AT THE CROSSING OVER THE STAFFORDSHIRE AND WORCESTERSHIRE CANAL, NEAR COOKLEY. *(Photo, by courtesy of Messrs. J. Mansergh and Sons.)*

The bridge is on the hydraulic arch principle. Only two of the three pipes are in use at present. At some river and stream crossings the third pipe was built in at the outset.

able curtain extending beneath the dam from end to end, and terminating in the hillsides. From the bottom of the curtain wall to the dam's crest the overall height at the centre of the dam is 212 feet.

The main aqueduct runs from the Howden reservoir to the service reservoir at Ambergate, whence the water is distributed to the towns of Derby, Leicester, and Nottingham. In its length of 30 miles there are 4 miles of tunnel 6¼ feet in diameter, 8½ miles of cut-and-cover, and 17½ miles of 45-inch steel pipe. The Leicester pipe is 33 inches, the Nottingham pipe 29 inches, in diameter. The branch between the service reservoir at Ambergate and Sheffield includes a tunnel 7,623 yards long. The cost of carrying out the scheme is estimated at £6,000,000 sterling.

Bradford's Supply.

Another important scheme is that which will supply Bradford with the water of the Nidd, stored up by a huge dam built across the river valley at a point 32 miles distant from the town. The aqueduct, which cost over half a million sterling, involved the driving of 6 miles of tunnel — one tunnel, that through the Greenhow Hill, being well over a mile long. As on the Derwent and Claerwen, other dams will be built and more water impounded when the demand comes for an increase in the supply.

[NOTE.—*Thanks are due to Mr. Walter Mansergh, M.Inst.C.E., and Mr. Martin Deacon, Assoc.M.Inst.C.E., for assistance given in connection with this article; to Messrs. James Mansergh and Sons for supplying a number of the illustrations; and to the Manchester, Birmingham, and Liverpool Corporations for permission to reproduce the sketch maps of the aqueducts.*]

THE TOWER BRIDGE.

PART OF THE ROOF OF THE HONOR OAK RESERVOIR, SHOWING ARCHES. (*Photo, Topical.*)

HOW LONDON GETS ITS WATER.

BY THE EDITOR.

This Article describes the development of the great system of Water Works by means of which over seven million people are supplied daily with more than thirty gallons each of wholesome, pure water.

IN previous articles have been described the great engineering works carried out to give New York and some of our greatest British cities an abundant supply of water. We have seen how the authorities responsible for the health of these cities have gone far afield to draw upon the resources of a suitable gathering ground.

It may seem strange, in view of these facts, that "Water" London, the greatest of all centres of human life, with its 514 square miles, and its population of over 7,000,000 people, should be able to derive most of the good water that it needs from within the area supplied. From the Thames, turbid and brackish as it passes through the heart of the city, nearly 130,000,000 gallons may be drawn daily at points just inside and outside the boundary line.* Wells sunk into the chalk that underlies the metropolis and its suburbs yield over 44,000,000 gallons in the twenty-four hours, and during the same period the sources of the river Lee supply some 50,000,000 gallons.

The Needs of a Huge Population.

It has indeed been a huge task to so organize and develop the supply that every individual of the 7,000,000 men, women, and children shall have on the average nearly 32 gallons for daily use. Every day 1,000,000 tons of water have to be pumped from wells and rivers into reservoirs, whence the flow descends by gravity through many thousands of miles of pipes,

Figures.

* The Metropolitan Water Board has an unrestricted right to take this quantity from the river, together with an additional 35,000,000 gallons daily for the Staines reservoir, or, by consent of the Local Government Board, 45,000,000 gallons.

spreading like an underground network in all directions, to hundreds of thousands of buildings. As mere numerals fail to convey an adequate idea of the quantity supplied, we may add that it would fill a canal 113 miles long, 20 feet wide, and 3 feet deep. To carry it, would be required a train of 203,600 trucks, occupying more than 800 miles of track, each truck containing five tons' weight of the liquid. A year's supply would form a lake about $3\frac{3}{4}$ miles square and 36 feet deep—of sufficient area and depth to give anchorage for all the battleships in the world.

Early History of the London Water Supply.

The early history of London's water supply is naturally very vague and indistinct. Occasionally there come to light pieces of the lead or earthenware pipes which, many centuries ago, distributed water within the walls of Roman Londinium. In those days plenty of clear, unsullied streams flowed through the area now covered by the great capital, and the inhabitants had no need to go far for their supply. Such also was the case as late as the reign of Henry II.; but when Edward I. was king the burgesses began to be exercised by the increasing pollution of the streams. In the middle of the thirteenth century leaden pipes were laid down between Tyburn springs and various points of delivery to the public in the city. A great conduit was built subsequently from the same source, through Charing Cross and the Strand to Fleet Street. As the pipes were in many places above ground and exposed to the air, they were often damaged by frost and accident, and left plenty of work to be done by the professional carriers who drew water for sale from the river.

London Bridge Water Works.

The first attempt to give London a reliable and organized supply seems to have been made by a foreign engineer, whose name was Anglicised into Morris. He had the sagacity to realize that the ebb and flow of the tides through the arches of London Bridge might be made to turn wheels and work pumps. The London Bridge Water Works, started by him in 1582, and developed gradually until the destruction of the bridge in 1822, proved so lucrative as to have the inevitable effect of raising up rivals to share in the profits of watermongering.

The New River Scheme.

In 1609 the Common Council granted to one Hugh Myddleton, a burgess of London and a jeweller by trade, powers to tap the Lee near Hertford, and lead water through an aqueduct about 40 miles long into the heart of the city. Myddleton lost no time in getting to work upon the construction of the New River, the name which the aqueduct then received, and which has clung to it ever since. The so-called "river" was, as a matter of fact, an open conduit of the Roman type, with a water surface following a uniform hydraulic gradient from end to end. For a large part of its length it took the form of an ordinary canal; at some points it ran through wooden troughs supported on wooden arches.

James I. assists.

The engineer had to face difficulties of the same nature as those which, many years later, overtook the first constructors of railways—owners of land objected strongly to the passage of the river through their properties, fearing evil consequences from outbreaks of water and the subdivision of their fields. It looked at one time as if Parliament would repeal the powers granted to Myddleton, whose anxiety was aggravated, after a year's work, by the exhaustion of his funds and the projection of a scheme to tap the Lee at Hackney. Feeling himself in a very tight corner, Myddleton applied directly to James I. for help. The king agreed to make himself responsible for half the expense and to take half the profits, while leaving the practical direction of affairs in the hands of his partner. Possibly even more valuable to

Myddleton than the pecuniary help was the royal protection thus assured against the promotion of rival schemes.

The New River completed.

On Michaelmas Day, 1613, the New River was opened officially, and its water admitted to the reservoir at Clerkenwell, whence wooden pipes ran to many points in the city. Its designer did not reap any great advantage from his enterprise, and died in debt to the Corporation of London for sums of money advanced to enable him to complete the work. But after the first period of adversity the New River went ahead—swallowed or destroyed smaller schemes that invaded its territory, and flourished exceedingly. In quite recent times the original shares in this company have changed hands at prices which may justly be described as fabulous, showing a greater rise in value over their issued price than can be boasted by the shares of any other commercial venture of which we have knowledge.

SIR HUGH MYDDLETON, THE DESIGNER AND CONSTRUCTOR OF THE NEW RIVER.

(Rischgitz Collection.)

For a considerable period the New River reigned supreme. The Chelsea Waterworks Company was incorporated in 1722. Large reservoirs were made in St. James's and Hyde Parks, and pipes were installed to distribute the water among a large number of houses in the Whitehall and Westminster districts.

Increase in the Number of Water Companies.

In 1745 a water business was established to supply the East End. Then followed a lull until 1785—when the Lambeth Waterworks Company received its charter—in the extension of waterworks, due no doubt largely to the difficulty of constructing machinery of sufficient power to pump large quantities of water at a moderate cost. Newcomen's "atmospheric" engine, much used during the earlier half of the eighteenth century for unwatering mines, was greatly improved upon by the invention of James Watt, who in 1769 patented his system of steam condensation in a chamber separate from the cylinder in which the vacuum formed was used. This simple but very important innovation, added to certain other improvements in mechanical detail, produced great economy in fuel consumption. By the end of the century the steam pump had become very efficient. It is not surprising, therefore, that in the early years of the nineteenth century several new water companies should have been formed. In 1807 the West Middlesex Waterworks Company was incorporated to supply the West End of London with water drawn from the Thames near Hampton. The year 1808 witnessed the in-

VIEW ON NEW RIVER AT HOE LANE PUMPING STATION.

In the foreground is one of the iron punts used by the walksmen who patrol the aqueduct.

the districts north of the Thames; the Kent, Southwark and Vauxhall, and Lambeth Companies the districts on the south side. In 1904 all the companies were bought out by the Metropolitan Water Board, established in 1902 to control the whole area, which is now divided into five districts—the Eastern, New River, Western, Southern, and Kent. (See map, p. 197.) As at present constituted, the Eastern district depends for its supply on the Lee, on eleven wells in the Lee Valley, and upon water drawn from the Thames at Sunbury and pumped through 36-inch mains to reservoirs at Finsbury Park. The New River district is fed by the river Lee, a spring at Chadwell, 18 wells in the Lee valley, and the Thames. The Western depends almost entirely on the Thames; the Southern on the Thames for about 97 per cent. of its supply, the rest being obtained from wells. The Kent district is peculiar in being supplied solely from eighteen wells in the chalk and one in the greensand.

Productive Wells.

Some of the wells in this area are extraordinarily productive. Nine furnish between them nearly 15,000,000 gallons a day. In depth, however, they do not approach the well at Streatham, which penetrates 89 strata, and is 1,270 feet deep. The amount of water obtainable daily from this well was at one time about 2,000,000 gallons. The private wells sunk and used in the Water London area contribute only very slightly to the total figures.

The water, whatever be its source, is pumped when ready for consumption to service reser-

corporation of the East London Waterworks Company, and 1809 that of the Kent Waterworks Company. The Grand Junction Waterworks, for the supply of Paddington, Marylebone, and adjacent parishes, date from 1811. Thus in the course of four successive years four important schemes materialized, and now London had a prospect of being supplied with an adequate volume of water for all purposes. The Vauxhall Waterworks Company, established at Vauxhall Bridge in 1805, and the Southwark Waterworks Company, formed at London Bridge in 1822, amalgamated in 1845.

It would be of little interest to review the gradual extension of the eight companies named above, which eventually parcelled out the area of what is known as Water London. Until recently the New River, Chelsea, East London, West Middlesex, and Grand Junction Companies, and the waterworks belonging to the Tottenham and Enfield Urban District Councils, supplied

The Metropolitan Water Board.

MAP OF WATER LONDON, SHOWING THE NEW RIVER, AND THE PRINCIPAL INTAKES, WELLS, PUMPING STATIONS, AND RESERVOIRS.

The five districts—the New River, Eastern, Western, Southern, and Kent—are named in large type, and their inside boundaries are indicated by fine dotted lines.

Reservoirs.

voirs scattered all over the area, and situated at a sufficient elevation to give a good "head" or pressure in the service mains. The Kent well water, being pure initially, is delivered direct to the service reservoirs; whereas that taken from the Thames and Lee flows or is pumped first into large low-level storage reservoirs—where a large proportion of the slight amount of suspended matter is deposited—and then is passed

THREE SETS OF MARINE TYPE TRIPLE-EXPANSION PUMPING ENGINES OF 550 HORSE-POWER EACH.

(Photo, Topical.)

The largest reservoirs yet constructed are the two at Staines. They have an area of 424 acres—about two-thirds of a square mile, and contain when full 3,338,000,000 gallons. The water is impounded by large banks of earth faced on the inner slopes with concrete blocks to withstand the action of the very considerable waves which arise when a high wind prevails.

Staines Reservoirs.

Far larger than either of the Staines reservoirs will be that now in course of construction near Chingford, to serve the Eastern and New River Districts. Its capacity will be approximately 3,000,000,000 gallons—equivalent to thirteen days' supply for the whole Metropolitan Water Board area—its surface 416 acres, and its greatest depth 34 feet. The first sod was cut by Mr. E. B. Barnard, M.P., the present Chairman of the Board, on April 11, 1908. The contract for the work was awarded to Messrs. Charles Wall, Limited.

Chingford New Reservoir.

The formation of the reservoir has necessitated the diversion of the Lee, which now flows round the eastern end of the site. A new channel, 3 miles long, 55 feet wide, and almost straight, is being cut; also an intake

through filter beds to pumps which deliver it to the high-level service reservoirs.

In the London area there are 1,497 acres of subsiding and storage reservoirs for unfiltered water, 59¾ acres of service reservoirs, and 164 acres of filter beds. To move the water, 265 engines, consuming annually nearly 160,000 tons of coal, and developing an aggregate of 38,361½ horse-power, are used.

channel from the Lee, an outlet channel 1½ miles long, and an overflow conduit.

The clay wall and the clay substratum form the sides and bottom of a gigantic and abso-

SIX-FOOT DIAMETER MAINS THROUGH WHICH WATER IS PUMPED INTO THE GREAT RESERVOIRS AT STAINES, NEAR LONDON.

(*Photo, by courtesy of Messrs. Thomas Piggott and Sons, Birmingham.*)

The largest constructional item is the raising of the 4½ miles of embankment required to impound the water. In the middle of the embankment is a vertical core wall of "puddled" clay, carried down at all points to the bed of London clay which underlies the surface of the ground at an average depth of about 20 feet. Up to ground-level the core wall is formed in a trench; above the surface it is built up simultaneously with the embankment. This last has a water slope of 1 in 3 and 1 in 4, and an outside slope of 1 in 2½. The earth needed for its construction—some 3,000,000 tons—is excavated by steam navvies and grabs and by hand from the bed of the reservoir, at a distance not less than 200 feet from the toe of the inside slope.

The Embankments.

lutely water-tight tank. The outward pressure of the water is borne by the embankment, which has on the reservoir side a facing of concrete slabs and bricks set in cement.

In order that the water may be drained away entirely if necessary, the bed of the reservoir will be given a gentle slope towards the southern outlet. The old bed of the Lee has been cleared out and filled up with hard earth of the same nature as the rest of the bottom.

Excavating.

An army of twelve hundred men, a multitude of locomotives and trucks—for which many miles of rails have been laid—and a large equipment of excavating machines, electric motors, and pumps, are, and will be for many months to come, engaged in the task of forming an arti-

MAKING THE TRENCH FOR THE LOWER PART OF A PUDDLED CLAY CORE WALL, CHINGFORD NEW RESERVOIR.

EXCAVATOR AT WORK AT CENTRE OF CHINGFORD NEW RESERVOIR.

ficial lake which will cover an area much larger than Hyde Park, and will contain more than half the volume of water stored in Lake Thirlmere. From Chingford the water will pass through an aqueduct to the great reservoirs at Walthamstow. The bulk will flow thence by gravity to the filter beds at Lee Bridge Pumping Station. At the Ferry Lane Station to the north of the main group of the Walthamstow lakes is a pump driven by a De Laval steam turbine, which

A Wonderful Steam Turbine.

will deliver 11,000,000 gallons of the Chingford water daily, when occasion requires, into the New River channel at Stoke Newington. It may be remarked in passing that this turbine is as notable for its small size as the Cornish engines at Lee Bridge are impressive by virtue of their great dimensions. A casing 4 feet in diameter, and but a foot or so long, houses a wheel which, rotating 7,500 times a minute, develops even more power than the "Prince" or the "Princess" described on a later page. This high-speed turbine, and the centrifugal pump which it drives, represent one of the latest developments in pumping machinery.

THE SUPPLY CHANNEL OF THE CHINGFORD NEW RESERVOIR.

The Beachcroft Reservoir.

The Beachcroft reservoir at Honor Oak, opened on May 5, 1909, is remarkable as being the largest covered reservoir in the world constructed at one time and under one contract. The main object of the reservoir is to supply water at low pressure to the south-eastern part of the Metropolitan Water Board's area. The water can, if necessary, be transferred to the northern side of the Thames by mains passing under the river.

The reservoir has a length of 824 feet, a greatest width of 587 feet, a water area of about 10 acres, a general depth of 21 feet 6 inches, and a greatest depth of 34 feet.

The first operation to be carried out was to excavate 173,000 cubic yards of earth and clay, which supplied the material for 19,000,000 bricks. On the north and on portions of the east and west sides, where the top of the reservoir is above the natural surface of the ground, embankments were built of alternate horizontal layers of earth and burnt ballast. Between the outside retaining walls and the ground a 3-foot wall of puddled clay was carried down to and into the London clay to form a watertight enclosure independently of the brickwork.

The Roof.

The whole of the bottom is covered by inverted arches of concrete crossing one another at right angles. At the points of intersection, $21\frac{1}{2}$ feet apart in both directions, rise brick piers of cruciform section, connected by arches running the whole length of the reservoir from east to

MAKING OUTLET CHANNEL TO THE CHINGFORD NEW RESERVOIR.

Earth excavated, ready for concreting.

CONCRETE INVERT OF THE OUTLET CHANNEL.

west. These arches and the piers carry the roof, which consists of a series of parallel brickwork segmental arches running north and south, covered with a 6-inch layer of cement concrete, above which is the clay and top soil originally taken from the site.

Two walls at right angles to each other divide the reservoir into four sections. At the point where the walls cross is a valve house for the valves controlling the supply, draw-off, and intercommunication of the sections, each of which can be filled or emptied independently of the others.

As the pumping stations, filter beds, etc., resemble one another closely in their general arrangement, and as the principles of filtering are the same in all gravitation filter beds, it will suffice to describe a single installation. For our example we may select the Lee Bridge pumping station, which is one of the chief feeders of the Eastern district.

Lee Bridge Pumping Station.

The station is divided into two parts by the river Lee, the main portion being on the north or Essex side, the smaller portion in Middlesex. Entering at the main gateway, we are confronted by a large engine-house, in which two great Cornish engines, the "Prince" and "Princess," have been busily at work since 1867 delivering water to a reservoir at Finsbury Park. Overhead rocks up and down the mighty beam of each engine, its ends pulled down alternately by the pressure of steam on the upper side of the piston in the single cylinder of 7-foot bore and 11-foot stroke, and by the 22-ton weight attached to the top of the 45-inch plunger. The steam serves merely to raise the plunger; the weight referred to does the forcing of the water—100 cubic feet, or about 600 gallons, per stroke—against a head of 140 feet. A Cornish engine has the disadvantage of occupying a great deal of room proportionately to its power, but is remarkably simple in its mechanism, and seldom needs any repair. Each engine is capable of delivering 10,000,000 gallons a day.

Cornish Pumping Engines.

RIVER LEE DIVERSION—ON RIGHT—WHICH CARRIES THE RIVER ALONG THE EAST SIDE OF THE CHINGFORD NEW RESERVOIR.
On the left is a tributary of the Lee.

Passing out of the engine-house, we are soon

PLACING THE STEEL RODS FOR A REINFORCED CONCRETE BRIDGE OVER THE RIVER LEE DIVERSION.

Washing is done either by subjecting the sand to high-pressure water jets, or by passing it through a mechanical washer of the type shown in one of our illustrations.

Mechanical Sand Washer.

The machine runs on rails round the edge of the central well. It consists of a large horizontal tube about 15 inches in diameter, inside which is an Archimedean screw driven through gearing by a high-pressure three-cylinder hydraulic engine attached to the carriage. The sand is lifted from the bed of the filter by means of a hydraulic ejector and deposited in a bin at one end, where it is caught by the screw and moved slowly along the tube, encountering in its passage the engine's exhaust water travelling in the opposite direction. The water picks up all the dirt and carries it away to a shoot emptying into a concrete conduit running parallel to the rails. The cleansed sand falls into a bin, from which it is scooped by an endless chain of buckets —also driven by the engine—and deposited at the edge of the filter bed, or in some other convenient place. One of these washers will deal with 50 cubic yards in a day. The filter beds of the station have a combined area of 24 acres. If all were in use simultaneously—an infrequent occurrence—they could deal with about one-tenth of the total London water supply.

on the edge of the first of the four groups of filter beds. Three of the groups contain six beds, arranged round a great circular covered well like the petals of an irregularly-shaped flower.

Filter Beds.

Strained water is admitted into these through culverts from an open aqueduct fed by the great Walthamstow reservoirs, $1\frac{1}{2}$ miles away to the north. Were our vision able to penetrate opaque objects, we should see the concrete floor of the filter, on that a 9-inch layer of large gravel, above that again 9 inches of small gravel, and top of all a couple of feet of sea sand. Every twenty-four hours about 1,000,000 gallons of water percolate through every acre of filter to the concrete bottom, along which it flows to a culvert communicating with the central well. From the well it passes to the sumps of the several pumps.

Once a month during the summer, and once in six weeks in the winter,* a bed is drained and a top layer, half an inch or so thick, of sand is scraped off, together with the superincumbent mud and other impurities—such as weeds—and washed for further use.

In other engine-houses on the Essex side are a pair of compound vertical engines; a pair of horizontal Worthington engines; a single horizontal tandem; a triple expansion engine of the marine type, known as the "Prince Consort," operating three pumps; and three vertical triple ex-

The other Pumping Engines.

* The period may be much longer or much shorter (in extreme cases, three weeks or several months), according to the weather prevailing.

RELIEVING ARCHES, NORTH-EAST RESERVOIR, HONOR OAK.

FLASHLIGHT PHOTOGRAPH OF THE INTERIOR OF THE HONOR OAK RESERVOIR, TAKEN AT THE OPENING CEREMONY.

This view shows one bay between two rows of piers, and also the roof arches.

(*Photos, E. Milner.*)

pansion engines with Corliss valve gear. These last deliver 12,000,000 gallons each per diem; the Worthington and the marine type units have a daily duty of about 10,000,000 gallons each. It may be noted that the "Prince Consort" and the three "triples" deliver water direct into the service mains, and not, as is usually the case, into a service reservoir. The speed of the engine is governed by the rate at which the water is drawn from the main. If the demand ceased altogether, the engine, which is designed to pump against a head of about 107 feet, would stop.

The Big Well.

Near the "Prince Consort" is a well, 11 feet in diameter and 200 feet deep. Through the chalk to which it reaches, horizontal headings have been driven in several directions. Their total length is about 1¼ miles. When the supply of river water is low, as sometimes happens in the dry season, this well is requisitioned. As many as 3,000,000 gallons have been raised from it by the twin pumps in a day.

Standpipes and Air Chambers.

Crossing over the Lee and the Hackney cut, we find a solitary Cornish engine, the "Victoria," delivering water to the Mile End, Stratford, Hackney, and other Eastern districts. In this case a standpipe, 4 feet in diameter, 120 feet high, and open at the top, serves to absorb variations in pressure—the water rising in the pipe during the delivery stroke of the pump, and sinking again during the suction stroke. The same system is used for the other two Cornish engines. Where the head of water is such that a standpipe of sufficient height cannot be provided conveniently, a large air chamber, mounted on the main, is employed to provide the requisite "buffering."

Turbines.

Among the machinery are two Girard water turbines, working two sets of three plunger pumps. They are driven by the fall of water over an adjacent weir in flood time. There are also two Hercules turbines driving four pumps for delivering water direct into the mains.

The Walthamstow Reservoirs.

In connection with the Lee Bridge pumping station should be mentioned the group of reservoirs at Walthamstow. There are twelve reservoirs in all, with a total area of 479 acres and a capacity at high-water level of 2,400,000,000 gallons. Six of them contain islands—formed by casting up part of the earth excavated from the sites—planted with flowering shrubs, limes, and willows. These islands are a beautiful feature of the landscape.

The reservoirs are fed by water from the Lee, and from two wells. One of the two pumping stations delivers water to reservoirs at Hornsey Wood and Haggar Lane; the other pumps to Ferry Lane and into the open aqueduct which connects the reservoirs with the Lee Bridge station.

Water Mains.

A few words about the mains which distribute the water. Their aggregate length is at present about 6,280 miles. In internal diameter they range from 54 inches to 2 inches. There are about 7½ miles of the 54-inch mains, as many of 48-inch; 108 miles of 36-inch; 84½ of 24-inch; 285 of 12-inch; and 3,000 miles of 4-inch, which diameter is most widely employed for the smaller mains.

The 3-inch pipes take second place with about 1,050 miles. If to the mains were added the lead piping for the house services, the total mileage would be somewhat astonishing. The very moderate average of three yards of lead piping for each man, woman, and child gives 21,000 miles; so that we may safely assume that the pipes used for the water supply of Greater London would suffice to encircle the earth.

The greatest pressures fall on the pumping mains, which in one case have to withstand a head of 600 feet.

A MECHANICAL SAND-WASHER. (*Photo, Topical.*)

A FILTER-BED READY FOR FLOODING. (*Photo, Topical.*)

A 40-INCH WATER MAIN. (*Photo, E. Milner.*)

In conclusion, despite the size of the works, the Water Board are considering extensions that will be necessary in the future. The Thames may be drawn upon still further, as the great chalk beds through which its upper reaches flow absorb heavy rain like a sponge, and pass the water out slowly to the river all the year round. These chalk deposits produce, in fact, the same effects as a dam, though in a very different way, and to them Londoners owe in no small measure the regularity of their water supply.

[NOTE.—*The author is greatly indebted to Mr. W. B. Bryant, M.Inst.C.E., Chief Engineer of the Metropolitan Water Board, for assistance given by him in regard to the preparation, revision, and illustrations of this article; also to Messrs. Charles Wall, Limited, for use of photographs.*]

CONSTRUCTING THE NEW HIGH-LEVEL OUTFALL SEWER FROM PLUMSTEAD TO CROSSNESS.
Putting in the concrete round moulds. (*Photo, E. Milner.*)

THE WONDERFUL DRAINAGE SYSTEM OF LONDON.

BY THE EDITOR.

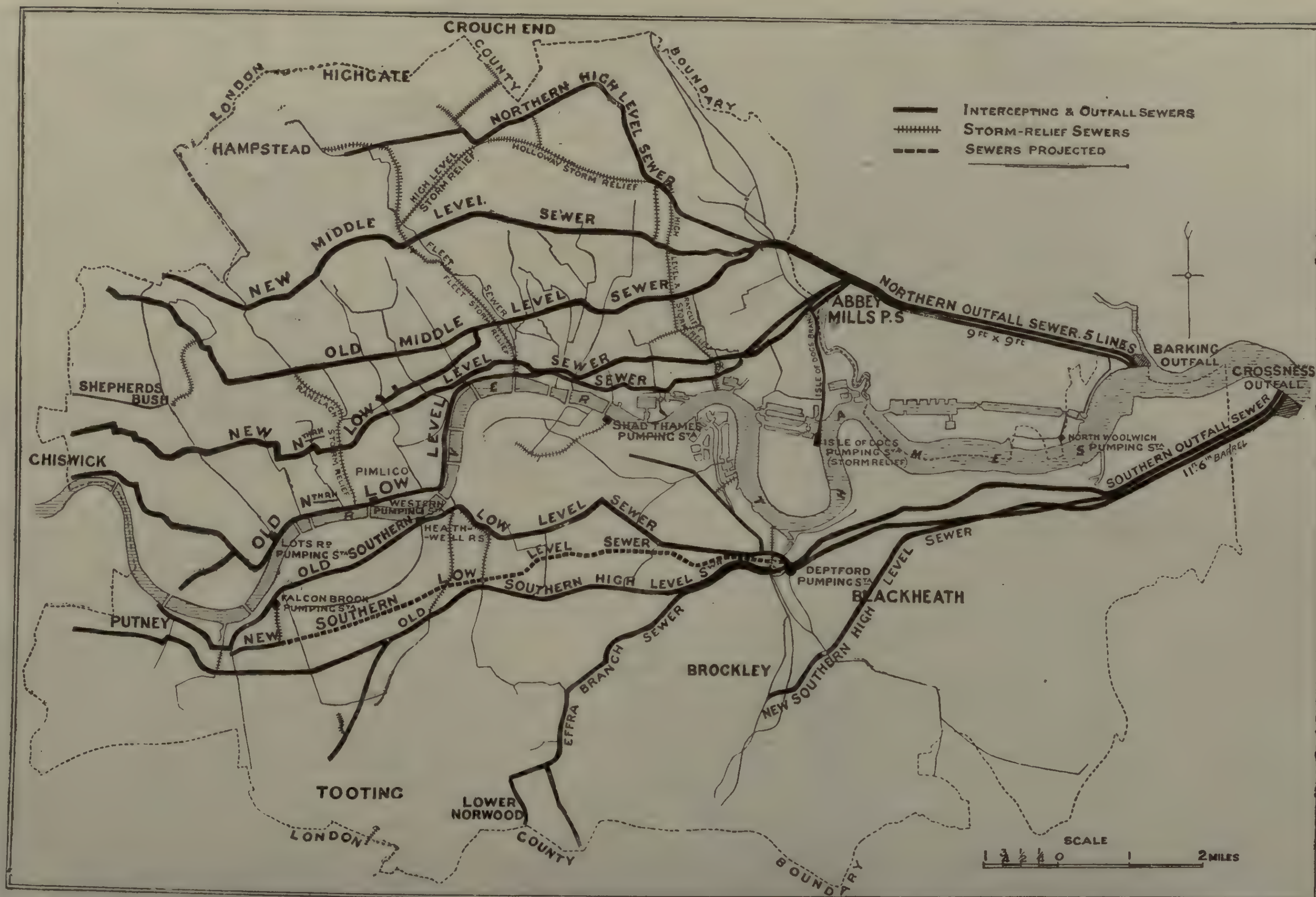
An account of the Works by which the Largest City in the World is drained, and of the system used for disposing of the vast quantity of Sewage that has to be dealt with daily.

THE prudent house-hunter is careful to investigate fully the water supply of any house in which he may be interested, and also its drainage system. The second is the complement to the first. The advantages of an abundant supply of good water are greatly lessened if there be no proper provision for carrying off all the water that may be used in the bathroom, sinks, closets, etc. For an isolated house a system of cesspools may serve, but where many dwellings are packed closely together some other method of getting rid of waste water and objectionable and dangerous sewage is necessary.

Water Supply and Drainage.

The problems connected with the drainage of London, the world's greatest and most populous city, have exercised for a hundred years or more the minds of the authorities responsible for its sanitation. It may be said with justice that the very improvement of the water supply has rendered these problems more and more difficult to solve; while the gradual covering in with houses and paved streets of 120 square

The Problem of Draining London.



MAP SHOWING THE INTERCEPTING, OUTFALL, AND MAIN STORM-RELIEF SEWERS OF THE LONDON DRAINAGE SYSTEM.

miles of the earth's surface has contributed in no small degree to the difficulties, since the rainfall on this great area must be dealt with by entirely artificial drainage. The rain that falls in a country district is mostly absorbed by the ground. Only when the fall is very heavy do the ditches fill and overflow. In a town a thunderstorm would soon convert the streets into lakes were not suitable arrangements made for carrying off the water as fast as it falls.

The old sewers of London were constructed to deal with the rainfall only, and mostly followed the lines of old water-courses. Early in the nineteenth century cesspools were introduced to receive the sewage from houses. Until 1815 the law forbade the discharge of house sewage into sewers; but as the cesspools proved to be quite insufficient for their purpose, legislation first permitted and then (1847) compelled house drainage to be discharged into the sewers. Within a period of about six years no fewer than 30,000 cesspools were abolished in the London area, and all house and street refuse was turned direct into the Thames.

The old Sewers and Cesspools.

Now, a large part of London lies so low that sewers running through it into the river must discharge below high-water level. This fact had most unpleasant consequences. Sewage could escape only at or near low water. As the tide rose the sewage from the high ground as well as the low was ponded back in the sewers. The heavier ingredients settled and accumulated. During rainy periods, and especially at high tide, the sewers overflowed into the houses. Even if the sewage did find its way into the Thames it was merely washed backwards and forwards by the tides, and served to form foul accumulations on the river banks.

Difficulty in discharging Sewage into the Thames.

At last the situation became so intolerable that public opinion demanded a remedy. In 1856 the recently formed Metropolitan Board of Works requested their chief engineer, the late Sir Joseph Bazalgette, to draw up plans for a system of discharging all the sewage of the Metropolis into the river at a point below London where it would prove less obnoxious.

Reforms urgently needed.

The fact that the land rises gradually from the Thames both northwards and southwards greatly assisted the evolution of a scheme of *intercepting* sewers running roughly west and east.

The scheme authorized in 1856 and executed between that year and 1874, may be summarized briefly thus.

On the north side were made three intercepting sewers—a high-level sewer, 7½ miles long, running from Hampstead to Old Ford, at which point it met a middle-level sewer, 9½ miles long, from Willesden, both of which sewers flow by gravitation. From Old Ford these two sewers discharged into the Thames at Barking through an outfall sewer, 5½ miles long, and consisting of two culverts 9 feet by 9 feet, from Old Ford to Abbey Mills, and three lines from the latter point to Barking, raised above ground in embankment. Closely following the north bank of the river for a considerable part of its course, a low-level sewer ran 13¼ miles from Hammersmith to Abbey Mills, a point on the main outfall sewer. As the area drained by this sewer is very low-lying, the necessary gradient to Abbey Mills would have been too deep for one lift, and to obviate this difficulty there was constructed an intermediate pumping station at Pimlico, raising the sewage west of this point about 19 feet into another sewer, which falls to 18 feet below Ordnance datum at Abbey Mills. Here the sewage is further raised a height of between 36 and 40 feet into the main outfall sewer referred to above.

The Present System of intercepting Sewers.

WEIR CHAMBER AT HAMMERSMITH ROAD—THE LARGEST YET BUILT. *(Photo, E. Milner.)*

In times of heavy rain the surplus which the main sewer cannot carry flows over the weir wall into the storm-relief sewer, from which it is discharged into the Thames.

On the south side the low-level, the high-level, and the Effra sewers, totalling, exclusive of important branches, 27 miles, met at Deptford. Here the first was pumped, and the two second discharged by gravitation, into the outfall sewer, which carried the sewage to Crossness. At Crossness all the sewage of South London had to be pumped to a level at which it could be emptied into the Thames. These three south intercepting sewers may therefore all be considered as low-level.

The general idea of the scheme was to separate the London area into strips, each of which should drain into an intercepting sewer passing along its river-side boundary. The main sewers, running north and south at right angles to the intercepting, were themselves fed by a ramification of local sewers serving every individual street. Water emptied down a sink, whether in Chelsea, Hampstead, Holborn, or Shoreditch, would eventually find its way to Barking, just as water from the roofs of houses in Walworth, Dulwich, and Bermondsey would in like manner be delivered at Crossness. There was no escape from the sewer network.

Sir Joseph Bazalgette based his calculations on a total population of 3,450,000 persons, and an average of 5 cubic feet (31¼ gallons) per day for every person. The intercepting and outfall sewers were designed to carry off 108,000,000 gallons per day in dry weather, allowing for the fact that the flow is much greater at some periods of the day than at others. Besides the actual sewage the rainfall had to be taken into consideration. The intercepting sewers and outfalls were

Storm Water.

ABBEY MILLS PUMPING STATION, WHERE THE SEWAGE FROM THE NORTHERN LOW-LEVEL SEWERS IS PUMPED INTO THE NORTHERN OUTFALL SEWER.

(*Photo, Pictorial Agency.*)

therefore made large enough to carry off some 286,000,000 gallons of rain water per day, in addition to the sewage. This quantity of water represents an average fall of one-sixth of an inch over the area drained. It was assumed, for the purpose of this calculation, that the rainfall would be equally distributed over the twenty-four hours of the day. We all know well enough, however, that a day of heavy rain means a fall greatly exceeding one-sixth of an inch, and that during a thunderstorm as much water will descend in a few minutes as is precipitated in a whole day of soft rain.

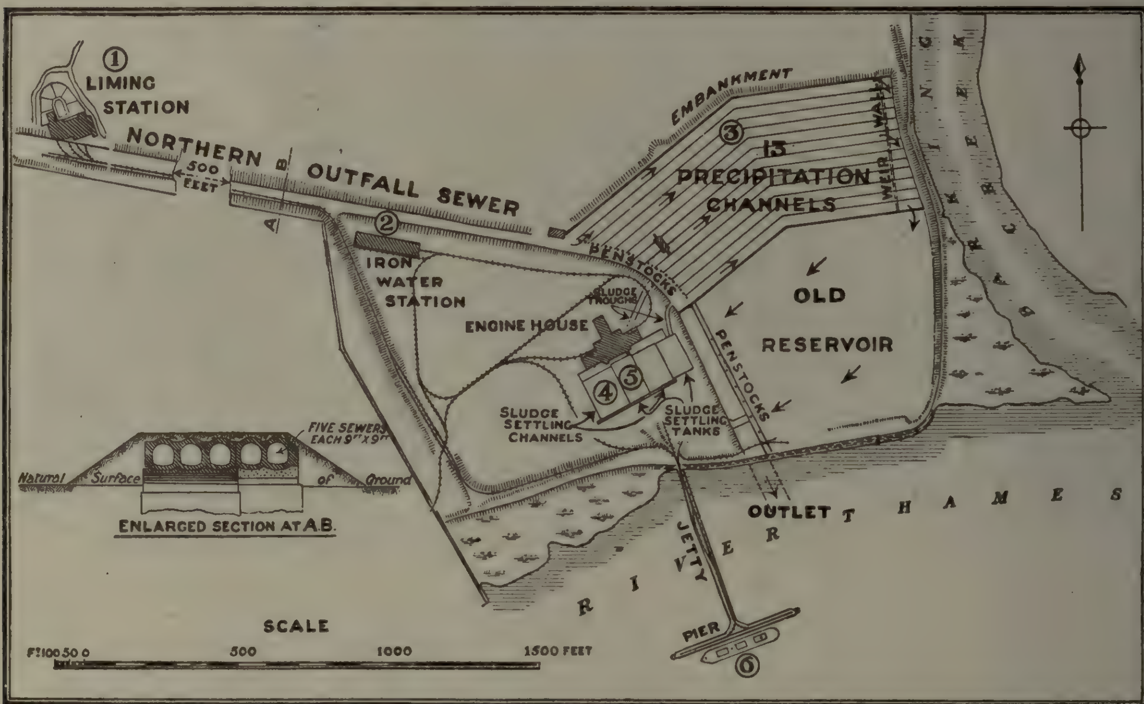
The old main-line sewers, which, as before stated, run from north to south on the north side of the Thames, and which originally discharged their contents into the river, are still utilized for carrying their sewage, but deliver into the intercepting sewers. When the flow in these main sewers and also the intercepting lines becomes too great, owing to excessive rainfall, to be discharged at the outfall, the excess passes into the river by means of the old outlets. For the purpose of obtaining additional relief in times of heavy rain, new storm-relief sewers have been constructed. Though this system of coping with heavy rainfalls was in a way a reversion to the old method, it must be noted that the discharge of the storm-relief and other sewers would not begin until the intercepting and main sewers had been well flushed by the first inrush of surface water. A compromise was inevitable. The 1891 report of the late Sir Benjamin Baker and of Sir Alexander Binnie stated that a rainfall of half an inch an hour, flowing off the area drained on the north side of the

Storm-Relief Sewers.

Thames (50 square miles) alone would require a channel 500 feet wide and 10 feet deep, and a flow velocity of 200 feet (about 2¼ miles an hour) per minute. This showed the impossibility of carrying off a maximum fall of considerably over one inch an hour through sewers designed to act as efficient channels for ordinary sewage.

of decades earlier. It was maintained that the river had been rendered dangerous to navigation and to health by noxious deposits. Inquiries held in 1869 and at later dates showed that, as regards the formation of mudbanks, the sewage was not responsible; but that about the seriously pol-

Pollution of the Lower Thames.



PLAN OF BARKING OUTFALL WORKS.

The large figures in circles denote the successive operations of liming, adding iron water, precipitation, sludge concentration, and delivery to the sludge vessels.

The completion of Sir Joseph Bazalgette's scheme closes what may be termed the second stage in the development of London drainage. Three huge culverts on the north, and one on the south, led all the crude sewage into the Thames at points about 14 miles below London Bridge—namely, Barking and Crossness.

Unfortunately for the Metropolitan Board of Works, the inhabitants of Barking presently began to complain that the enormous volume of pollution transferred to this locality reproduced there the very unpleasant state of things against which Londoners had rebelled a couple

luted condition of the river there could be no doubt. In 1884 the Commissioners appointed to investigate the matter reported that London sewage ought not to be discharged in its crude state into any part of the Thames; that the solid matter should be separated from the liquid by some process of deposition or precipitation, and be applied to the raising of low-lying lands, or be burnt or dug into the land, or carried away to sea; that the liquid portion of the sewage might be allowed to pass into the river after being chemically clarified.

As a result of this report the Board deter-

DIVERSION CHAMBERS ON NORTHERN OUTFALL SEWERS NEAR ABBEY MILLS.

mined to construct chemical precipitation works at both Barking and Crossness. Those at the northern outfall were begun in 1887 and completed about the end of 1890, by the London County Council, which succeeded the Metropolitan Board of Works in 1889; while the Crossness works were commenced in 1888, and were ready for operation by 1891.

The Chemical Treatment of Sewage introduced.

The treatment of sewage in such a way as to render it practically innocuous is carried out on so colossal a scale at Barking and Crossness that no apology is needed for describing a process which, though unsavoury, is by no means devoid of interest. The diagram of the Barking Outfall Works, reproduced by the kind permission of the London County Council, will assist the reader to follow the course of operations.

On its way from Abbey Mills the sewage passes by a liming station, where there is an elaborate installation of machinery for churning lime and water together to form a milk-coloured liquid, containing about 110 grains of lime to the gallon of water. This liquid is run into the crude sewage in such proportions that there shall be about four grains of lime to the gallon of sewage, which means the consumption of 14,800 tons of lime yearly at the Barking works.

Barking Outfall Works.

A further addition is made to the sewage of a solution of sulphate of iron, in the proportion of one grain of sulphate to the gallon of sewage—3,300 tons of the chemical being used in a year. The lime and iron together precipitate the solid matter.

At the Barking outfall are thirteen precipitation channels, varying in length from 1,200 to 860 feet, and 30 feet wide. Their united capacity is 20,000,000 gallons. The channels are separated from one another by walls, and are roofed over. At the sewer end of each are two penstocks or inlet valves for admitting sewage; at the other end is a weir wall over which the effluent—that is, the clarified sewage after precipitation of the heavier matter—passes through old reservoirs into the river. The channels are closed in rotation once in about sixty hours—the period varies according to the nature of the sewage and of the weather — for the treatment of the precipitated sludge.

Precipitation Channels.

When the penstocks of a channel have been shut, the top water is drained off through

VIEW FROM THE INTERIOR OF A NORTHERN OUTFALL SEWER DURING CONSTRUCTION.

THE CAST-IRON TUBES OF THE TWO NEW LINES OF THE NORTHERN OUTFALL SEWER. USED ON THE BRIDGE OVER THE LONDON, TILBURY, AND SOUTHEND RAILWAY.

The three old lines are in the embankment to the right. Tubes ready for testing with water.

lowering weirs into a culvert leading to the river. When all the top water is gone, the "wet sludge" left is pushed, by means of large squeeges, along the channel to the sump of the sludge pumps. On its way to the sump the sludge traverses a screen, which arrests all rags, wood, and

The Sludge.

DISCHARGING SLUDGE INTO STEAMER AT BARKING. (*Photo, Pictorial Agency.*)

other things which might damage the pumps. These last deliver the sludge into setting channels, where a further deposition of the solid matter takes place. The supernatant "liquor" is drawn off by telescopic weirs, given a stiff dose of lime and iron, and returned to the sewer to pass through the precipitation channel again with other sewage. The sludge is then pumped into overhead tanks, from which it runs by gravity, or is pumped from the sludge channels direct through pipes, into specially constructed tank vessels, holding about 1,000 tons each, which formerly steamed down the river to a point called the Barrow Deep, about 57 miles below Barking, but now deposit the sludge in the Black Deep, about 5 miles further out to sea, over a length of from 8 to 10 miles.

The sludge vessels are loaded through hatchways in two cases, in others through a central hopper. At the bottom of a hopper are four rectangular valves, each governing the inlet to one of the four compartments into which the vessel's tank is divided by a longitudinal and a cross bulkhead. The two triple-expansion 500-horse-power engines are aft of the tank. Between the forecastle and the tank is a large water-ballast tank of 170 tons capacity. The *Burns*, the latest addition to the fleet, is fitted with electric light throughout, and contains a saloon, two staterooms, bathrooms, and other luxuries which one would

Sludge Vessels.

INTERIOR OF LOT'S ROAD PUMPING STATION FOR DEALING WITH STORM WATER.

The eight gas engines seen in the picture have a total horse-power of 1,880, and are able to deliver 152,000 gallons per minute into the Thames.

THE BRIDGE WHICH CARRIES THE FIVE LINES OF THE NORTHERN OUTFALL SEWER ACROSS THE LONDON, TILBURY, AND SOUTHEND RAILWAY, AT A POINT JUST WEST OF PLAISTOW STATION.

not expect to find on a vessel designed for such a purpose.

A vessel is able to discharge its 1,000-ton burden in a minimum time of six minutes. In practice the operation takes about an hour, the boat steaming along at normal speed meanwhile to distribute the sludge over a large area. The sea-water has been analyzed after deposit of the sludge without revealing any traces of the impurity, nor has a particle of sludge been discovered on the shore of the Maplin Sands. This proves conclusively enough that all organic matter must be well assimilated by the German Ocean, though the sludge carried out to sea annually would suffice to cover Hyde Park to a depth of nearly five feet. Each of the sludge ships reports to the Mouse Lightship every time it passes outward or inward bound, by flags in the daytime, by flashed Morse signals at night. The time of passing the Mouse is noted for comparison with reports sent by the London County Council to the Thames Conservancy (now the Port Authority), which body is also informed of the number of times each vessel is loaded at the outfall works.

Dumping the Sludge at Sea.

The effluent from the sewage is, when it passes into the Thames, remarkably clear and transparent. In fact, it has been said that it is the clearest water that enters the Thames below Richmond. Fish, which previously to the establishment of the precipitation works did not come farther up the river than Gravesend, now pass up to London Bridge—a striking testimony to the improvement effected by the new system of sewage disposal.

The outfall works at Crossness are in principle identical with those at Barking as regards both their arrangement and the treatment of sewage, but more compact. It should be noted, however, that whereas on the north side of the river all the sewage flows by gravitation from Abbey Mills to the precipitation channels, at Crossness it has to be pumped.

New Sewers.

Recently two new sewers, each 9 feet by 9 feet, have been added to the northern outfall sewer between Old Ford and Barking, and are now in use. These, like the old culverts, are carried in embankment some 20 feet above the surrounding district, and cross over numerous roads, railways, and water-ways by means of iron tubes carried on girders and supported by abutments. A new middle-level sewer, which will discharge by gravity, is being made from Willesden to Old Ford, a distance of nine miles; and a new low-level sewer, 12¼ miles long, is under construction between Hammersmith and Bow. On the south side of the river a new outfall, 11½ feet in diameter, now runs from Deptford to Crossness, and a new high-level sewer from Catford to Crossness. Plans have been drawn up for an additional low-level sewer between Battersea and Deptford. The map on page 210 shows the positions of all the intercepting and outfall sewers quite clearly.

Sewer Construction.

The older intercepting outfall sewers were made of brickwork, either in cut-and-cover tunnel or in embankments, according to the level of the ground surface. For the new northern low-level intercepting sewer the tunnelling shield and a cast-iron lining, concreted on the inside, have been used. In fact, its construction differs little from that of the tunnels of a tube railway except that the spaces between the flanges of the cast-iron lining are filled in and rendered to a smooth surface. The cross-section of the intercepting sewers increases gradually eastwards. Thus, the old middle-level begins with a 4½ by 3 feet section at the western end. North of Kensington Gardens the figures increase to 6 feet by 4 feet. Abreast of London Bridge there is a 9-foot barrel; and by the time the junction with the high-level sewer at Old Ford is reached the dimensions have risen to 9½ feet by 12 feet.

CONTRACTOR'S ELECTRIC TRAM IN THE SOUTHWARK AND BERMONDSEY SEWER.
SHIELD USED FOR DRIVING THE NEW SOUTHWARK AND BERMONDSEY RELIEF SEWER.

(*Photos, E. Milner*)

At present the outfalls have a total discharging capacity for sewage and rain water of 1,000,000,000 gallons a day. In addition, pumping power has been provided for lifting 456,000,000 gallons a day of rain water from the storm overflows into the river

The sewers under the control of the London County Council (of which Mr. Maurice Fitzmaurice, C.M.G., M.Inst.C.E., is chief engineer, Mr. J. E. Worth, M.Inst.C.E., district engineer, having charge of the district on the north side of the Thames, and Mr. R. M. Gloyne, M.Inst.C.E., of that south of the river), are: 216 miles on the north side of the Thames and 129 miles on the south, making a total of 345 miles of main and intercepting sewers. It must be remembered that in addition to the above there are all the sewers, one in each street, which discharge into the main-line sewers. These local sewers are under the control of the Borough Councils, and, although small, are, of course, of considerable length, totalling in the aggregate about 2,000 miles.

The Sewermen's Duties.

The men who work in the sewers are called "flushers"—though not much flushing, in the general acceptation of the term, is required where the flow is so considerable as that in the Council's sewers. The principal duties of these men are to remove the large quantities of "detritus"—sand, gravel, and macadam—which finds its way into the sewers through the surface gratings and street gullies. Many thousands of cubic yards are removed annually. This work is generally carried out during the night, and involves some difficulty and danger.

Dangers.

The large flow of water in the sewers and the possibility of a sudden influx of storm water render the greatest precautions necessary. Life-lines are always kept handy, and permanent safety-bars are built into the sewers, across which they are placed when the men are at work.

Other dangers arise from the discharge of hot water and steam, though by the General Powers Act of 1894 manufacturers are prohibited under penalties from releasing into the sewers anything of a temperature higher than 110 degrees Fahrenheit, or any chemical or manufacturing refuse that might involve risk of injury to the men working underground.

Again, there is the danger connected with the possible presence in the sewers of inflammable gases and of the waste from inflammable liquids. This risk, which has been considerably augmented by the great number of petrol-driven vehicles, is guarded against by the use of special safety lamps. Thanks to the elaborate precautions taken, accidents of a serious character are very few in number, and the health of the men is generally good. During the summer months all the sewers are deodorized as much as possible by the addition to the sewage of quantities of permanganate of potash, carbolic powder, and other disinfectants.

Pumping Stations.

The chief pumping stations for dealing with sewage and flood water are interesting on account of the vast volumes which they have to lift. The western station, at Pimlico, on the northern low-level sewer, contains four single-acting beam engines of 90 horsepower each, with steam cylinders of 37-inch diameter and 8-foot stroke. Each engine operates two pumps. To provide for possible breakdowns, an auxiliary engine of 120 horsepower is kept in reserve. The whole installation is able to lift 54,000,000 gallons of sewage a day 18 feet to the head of the second section of the sewer running to Abbey Mills. The latter pumping station, which covers about seven acres of ground, is a very handsome structure both inside and outside.

Abbey Mills.

The engine-house has a cruciform shape, each of the four arms housing two large beam engines, with beams parallel to one another. All the steam cylinders are

SUBSTRUCTURE OF NEW NORTHERN OUTFALL SEWERS, NEAR HIGH STREET, STRATFORD.

at the inside end of their respective beams, arranged symmetrically round the centre of the building under the dome. The total horse-power of the eight engines is about 1,100, and their capacity 135,000,000 gallons a day. In a separate building of later date two triple-expansion Worthington engines have been installed, to make the total power available at this station sufficient to raise 171,000,000 gallons per day through a vertical distance

of 40 feet from the low-level sewers into the outfall sewer. As at the Western, Crossness, and Deptford pumping stations, all sewage is passed through screens before it reaches the pumps. From year's end to year's end some or all of the pumps are busy—busiest during the working hours of the day and when rain falls heavily, idlest during the small hours of the morning.

The drainage of the isolated portion of North Woolwich (Silvertown), which comprises also parts of West and East Ham, is dealt with at a station in that area, known as the North Woolwich pumping station. Here there are three vertical triple-expansion engines capable of discharging 4,500,000 gallons per day through two 14-inch diameter pipes into the Barking outfall works. In addition to these engines there are centrifugal pumps to discharge storm water into the river in times of heavy rainfall.

Second only to Abbey Mills in pumping capacity, on the north side of the river, is the Lot's Road station, Chelsea. This was opened on February 20, 1904.

BRICKING ARCH OF NEW HIGH-LEVEL SEWER FROM PLUMSTEAD TO CROSSNESS. (*Photo, E. Milner.*)

Lot's Road Pumping Station.

A sewer—the Counter's Creek Sewer—commences near Kensal Green, and runs for about 4½ miles in a southerly direction, draining an area of about 5 square miles, to Lot's Road, where it discharges into the low-level intercepting sewer. In times of heavy rain the Counter's Creek sewer brings down much more water—some 12,000 cubic feet per minute—than the low-level intercepting sewer can deal with ; hence the neces-

sity to lift this water into the Thames. The Lot's Road station contains eight large centrifugal pumps, able to discharge each 3,200 cubic feet (about 19,000 gallons) a minute, rope-driven by twin-cylinder gas engines built on the "Otto" principle. Four of the engines develop 260 horse-power; four, 210 horse-power. The more powerful engines pump from the Counter's Creek sewer, the others from the low-level intercepting sewer, into the Thames. Compressed air is used to charge the pumps with water and start the engines. Twenty to thirty minutes suffice to get all the pumps to work. When steam-power is used at a storm-water pumping station—as in the Isle of Dogs—the fires must be kept banked ready for any emergency, a course which entails heavy expense in fuel; whereas the gas engine is ready to start at a moment's notice, and costs nothing when not running. Therefore it is improbable that any more steam engines will be installed for dealing with the discharge of storm water into the river in future.

Adjoining the Deptford Creek is the Deptford pumping station, in which are six main pumping engines capable of raising 193,000,000 gallons of sewage daily to a height of about 20 feet.

At Crossness—where, as we have stated already, all the sewage from the southern district has to be lifted—is the largest of the pumping installations. Here are six engines, of which four are beams and two triple-expansion vertical engines. The total pumping capacity of these six engines is 250,000,000 gallons per day. The lift is about 21 feet. Each of the beam engines has two pump plungers 9 feet in diameter, which probably makes them the largest pump plungers in the world as regards diameter.

Crossness Pumping Station.

In addition to the stations mentioned above are those for dealing with storm water at Heathwall, Nine Elms Lane, King's Scholar's Pond, Pimlico, Falcon Brook, Battersea, and Shad Thames, Bermondsey. Plans for a storm-water pumping station at Abbey Mills, capable of raising 150,000 gallons a minute, are in course of preparation.

The problem of draining London has indeed been a difficult one to handle, but it has been solved in a most masterly and efficient manner. At the beginning of this century about 5,140,000 people inhabited the area to be drained *—the total has increased considerably since then—a population equal to that of Glasgow, Liverpool, Manchester, Salford, Leeds, Birmingham, Sheffield, Newcastle-on-Tyne, Bristol, Hull, Dublin, Belfast, and Edinburgh combined—or, in other words, to eight times that of Glasgow. Every day of last year an average volume of nearly 300,000,000 gallons of sewage had to be treated at Barking and Crossness, and all the huge amount of solid matter abstracted and carried out to sea. It is indeed difficult to appreciate the vastness of the work and its maintenance for which the London County Council is responsible in connection with the sewage of the Metropolis. Despite its huge area and population, London is one of the healthiest cities in the world; and that this is due largely to the excellent drainage must be apparent from a comparison of the following death-rate statistics with the development of the drainage works.

Figures.

Prior to 1874—in which year Sir Joseph Bazalgette's scheme of intercepting sewers was completed—the average annual death-rate per thousand in the Metropolis was about 24. During the decade 1871–80 the figures fell to 22·5. The works for treating sewage chemically and carrying the sludge to sea were completed

Effect of Good Drainage on the Death-Rate.

* This includes, besides the county of London, Acton, Wood Green, Tottenham, West Ham, Penge, and parts of Willesden, Hornsey, East Ham, Croydon, and Beckenham—an area of about 31 square miles. The total area drained is about 150 square miles.

CUT-AND-COVER WORK FOR THE NEW SOUTHERN HIGH-LEVEL INTERCEPTING SEWER, BETWEEN CATFORD AND BLACKHEATH.

(*Photo, E. Milner.*)

at Barking and Crossness in 1890 and 1891 respectively. The decade 1891–1900 had an average death-rate of only 19·1 per thousand; and the improvement has been rapid ever since. Last year the rate had fallen to the unprecedentedly low point of 13·8, or 11 per thousand less than in 1841–50. These figures surely speak for themselves; and Londoners have little reason for grudging the £11,000,000 odd spent on works which carry away foul water and matter from their homes, offices, factories, and streets.

The staff engaged on the drainage works of London is made up of 456 men on the north side of the Thames, 335 on the south side, and 150 men on the sludge vessels—a total of 941. Their work proceeds night and day incessantly.

[*Thanks are due to Mr. John E. Worth, M.Inst.C.E., District Engineer in charge of the Drainage Work on the north side of the Thames, for valuable help given in connection with the preparation and illustration of this article.*]

THE ELECTRIC POWER STATIONS OF LONDON

BY E. LANCASTER BURNE, A.M.Inst.C.E.

VIEWED collectively, the arrangements for supplying our greatest city with electricity are almost overwhelming in their magnitude. Contained within some forty power-stations are nearly 1,000 boilers and over 500 engines and dynamos, to say nothing of the various pumps, coal-handling appliances, and other accessories.

Some Figures.

The total horse-power of the engines is, in round numbers, two-thirds of a million, so that each inhabitant is represented by about one-tenth of a horse-power, which is the equivalent of his own best muscular effort. To distribute the electric current, each station has a network of from 100 to 200 miles of cable; with a few the length is even greater.

After giving these preliminary figures, we will consider shortly the electrical requirements of London, before examining the methods by which they are fulfilled.

Although electricity is now used in many processes, illumination and transmission of power are its chief applications.

Uses of Electricity.

Electric lighting, both public and private, is now so universal that every one is familiar with its extent. Electrical transmission of power has, in a comparatively few years, almost revolutionized travelling in London; but we so soon grow accustomed to improvements that they are usually accepted as a matter of course. Who of us, however, would welcome a re-adoption of steam locomotives on the District and Metropolitan Railways, or a return to the times when "tube" railways were not? Again, compare the modern electric tramcar with the horse-drawn variety.

The route length of electric railways in and around London is now 157 miles, and there are approximately 160 miles of electrified tramway track; also a large number of electric road vehicles. Add to these the innumerable electric motors operating all kinds of machinery—such as lifts, printing-presses, etc., many of them in places where a steam engine and boiler, or even a gas engine, would be inadmissible. The enormous current required for the myriad lights, the constant and heavy traffic, the multitude of motors and various other appliances, is derived almost entirely from the public supply.

Systems of Distribution.

Three general systems for the distribution of electrical energy obtain in London; these are the *low-tension direct current, the high-tension alternating current,* and a system combining the two. In the simplest form of the direct

system, electricity is generated at a *voltage* (or pressure) somewhat higher than that required by the consumers' lamps, etc., as there is a slight loss in transmission. This method is suited for very short distances only, as the sectional area of each conductor, or *main*, must be sufficient to carry, without undue resistance, a current or quantity of electricity equal to that used at the lamps. The above system, which is known as the "*parallel*," has been almost altogether superseded by the "*three-wire*" system. In this, electricity is generated by two dynamos joined in "*series*"—*i.e.*, two of their terminals are connected so that the current passes through both machines. This arrangement doubles its pressure but does not alter the quantity. Two conductors, which may be called the "*outer*" wires, are taken from the remaining terminal of each machine, and a third from the cable which joins them in series. If the voltage of each dynamo is, say, 200, the pressure at the "*positive*" outer conductor will be 200 + 200 = 400; that of the middle or third wire, 200; and that of the "*negative*," or return, outer wire, 0. There will thus be a *potential*, or pressure, difference of 200 volts between each two neighbouring conductors. From this it will be obvious that 200-volt lamps may be connected to the third and to either one of the outer conductors, in spite of the fact that the potential difference of the two outer conductors is 400 volts. The importance of this is that the capacity of the two outer conductors is, at 400 volts, twice as great as it would be if used in a parallel system at 200 volts, because their sectional area is proportional to the quantity, and not to the pressure, of the current they have to transmit. A higher voltage than 250—the present limit of the ordinary incandescent lamp — would be undesirable for domestic use. Electric motors are, however, nearly always "wound" for double the lamp voltage, and connected to the outer wires of the system.

The Three-wire System.

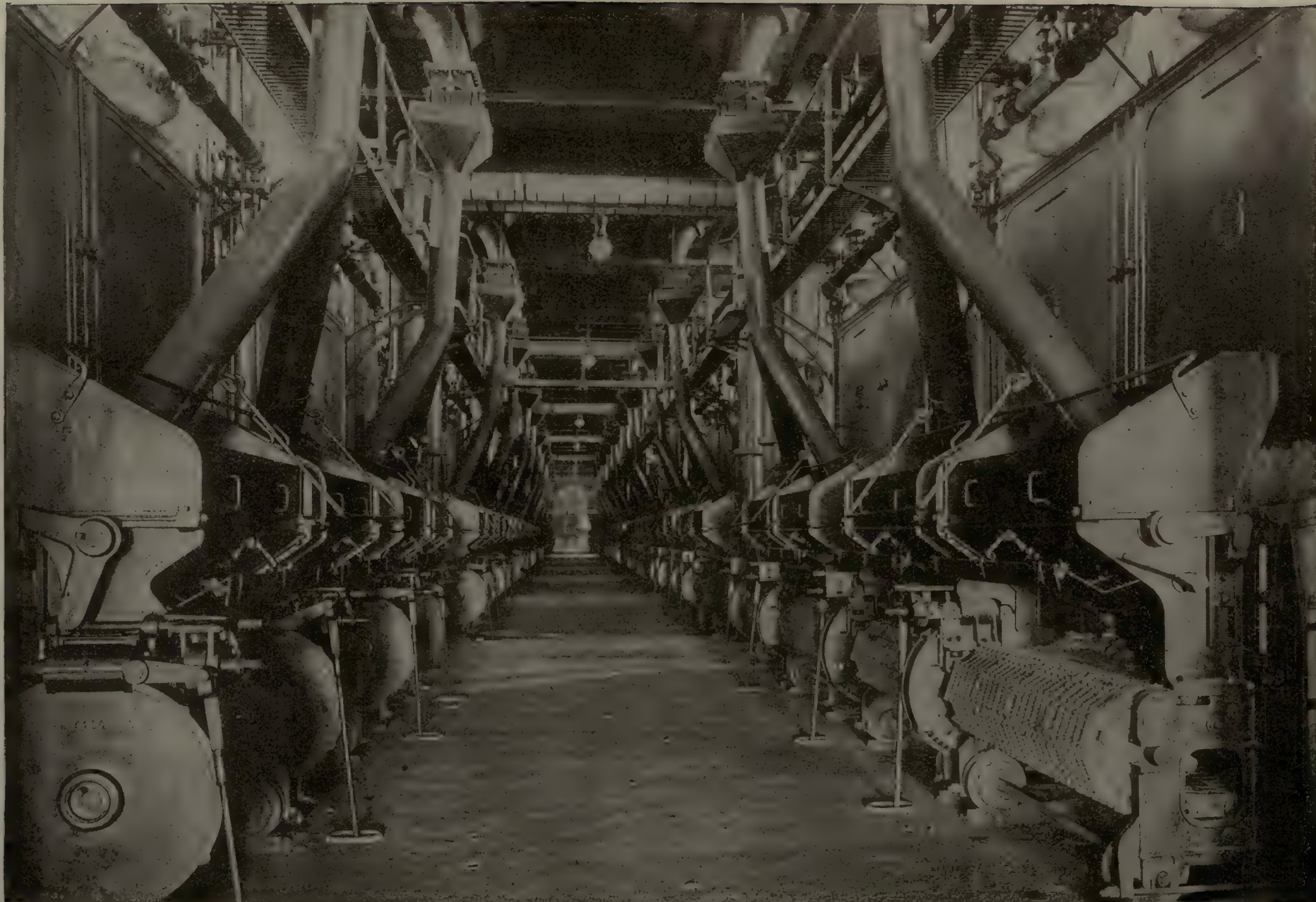
We must now pass on to the alternating system of distribution. The difference between this and the direct system is that, instead of a continuous, one-direction current, a series of currents, moving alternately in opposite directions, is set up in the conductors. Two complete reversals form a "*period*" or "*cycle*," and the number of these cycles varies from 50 to 100 per second. The most important feature of the alternating current is that the voltage may be raised or lowered, and the current diminished or increased in the inverse ratio, by a "*static*" transformer, which is a simple apparatus constructed upon the principle of the induction coil, but containing no moving parts.

Alternating Current.

To transform a high-tension *direct* current to one of low voltage would require a motor suited to the high voltage, and a dynamo designed to give a lower voltage with an increase in current. In other words, it would be necessary to convert electrical energy into mechanical energy (by the motor), and reconvert this mechanical energy into electrical energy (by the dynamo)—a somewhat inconvenient process compared with the direct method of the static transformer. Owing to the facility with which the voltage of an alternating current can be changed, it is essentially suitable for long-distance transmission, as will be seen later.

Transformers.

In some cases the tension adopted is extremely high; for instance, at the Deptford station of the London Electric Supply Corporation the current is generated at 10,500 volts for transmission to various sub-stations, some in the heart of the Metropolis. From the sub-stations the current is distributed, at a reduced tension, by the network of street mains in their immediate neighbourhood. The tension, still high, is further reduced at each house connection by a small transformer in



LONDON ELECTRIC UNDERGROUND RAILWAYS: LOT'S ROAD GENERATING STATION, CHELSEA. THE BOILERS AND MECHANICAL STOKERS.
(*Photo, E. Milner.*)

the basement. In this way an immense quantity of energy may be transmitted by means of a comparatively small wire, and a vast saving effected in the initial outlay on that expensive metal, copper.

The periodicity of the current supplied from Deptford is 85; that is to say, a "wave" of electricity flows back and forth from the generating station through the whole network of mains (about 160 miles) and the wires on the consumer's premises, 85 times a second.

It is fairly safe to prophesy that in years to come the existing power-stations in London will tend to become merely distributing centres for their vicinity. Huge power-stations, far from the Metropolis, in places where land is cheap, and fuel and water more readily obtained, will probably supply the present stations with high-tension current in bulk. Such a scheme was, to some degree, shadowed forth in a recent proposal of the London County Council; and a beginning of it may be seen in the case of the Central Electric Supply Company, which, from a generating station at Marylebone, supplies additional current to the St. James's and Pall Mall Electric Lighting Company and the Westminster Electric Supply Corporation. In this instance a high-tension alternating current (6,000 volts) is conducted to sub-stations in the districts of the two latter companies, at which it is changed to a low-tension direct current for distribution by the existing three-wire system.

Future Supply.

This affords an example of the combined system of distribution previously mentioned. The conversion at the sub-stations of alternating to direct current is accomplished by causing the former to drive an alternating-current motor, the shaft of which is coupled to a direct-current dynamo. Such a combination is termed a "*motor-generator*."

The question now arises, why should direct current be used in some districts and the alternating in others, when the conditions are about the same throughout? Perhaps the best answer that can be given is that, in the early days of commercial electricity, lighting formed the chief business, for which purpose direct and alternating currents were equally suitable, apart from the advantages possessed by the latter in regard to transmission. But when the electric motor came to be applied to industry, a stimulus was given to the direct-current system, as the alternating-current motor had not then been developed on practical lines. Further, it was, and still is, impossible to charge secondary batteries with an alternating current. By the use of a rectifier, however, an alternating current can be changed to a direct current for that purpose.

Alternating and Direct Currents both needed.

The difficulties connected with alternating-current motors have now been overcome, but a change of system would be attended with inconvenience, so that, although alternating current is, in some cases, supplied by trunk mains to the sub-stations of direct-current systems, it is converted before its distribution through the network. Occasionally—for example, the North and the South Metropolitan Electric Light and Power Companies, which supply a large suburban area—generating plant for both alternating and direct currents is installed at the power-station.

It is some twenty years since the public supply of electricity was commenced in London, and power-stations are still being erected. Many improvements have taken place during this period, and although London is, in the opinion of most people, adequately supplied in this respect, the result is due not to any one general scheme, but to a great number of small schemes carried out in many ways, and owned by various companies and authorities.

To describe adequately the manner in which the Metropolis is supplied with electricity would require a more or less detailed account of each of the thirty-four areas supplied by the several

lighting companies and borough councils of Greater London. Most of the tramways and electric railways have their own generating stations, but some purchase current in bulk from the supply companies. Thus the Metropolitan Electric Tramways derive their current from the North Metropolitan Electric Power Supply Company, and the newly electrified South London line of the London, Brighton, and South Coast Railway Company will be supplied with energy by the London Electric Supply Corporation.

Five electric railways—namely, the "Bakerloo," the "District," the "Great Northern and City," the "Hampstead," and the "Piccadilly"—are worked from one generating station; and to these systems will be added others authorized but not yet constructed. As this station is one of the most modern and by far the largest in London, we propose to take it as an example, and to describe it at some length.

Lot's Road Power-Station.

This immense power "factory" occupies nearly four acres of land adjoining the Thames at Chelsea. On account of its four lofty chimneys, which are each 275 feet high, it is a very conspicuous, if not picturesque, object in the landscape, and some one has compared its general appearance to an inverted table of Gargantuan proportions.

Coaling Facilities.

The site, Chelsea Creek, is a fortunate one, as it is fairly well placed relatively to the electric railways concerned, and at the same time has the advantages of a river frontage and proximity to the West London extension of the North-Western Railway. Coal can therefore be delivered by water or rail, and special facilities exist for handling it. In the case of water-borne coal, the barges are received into a tidal basin, spanning which are two travelling cranes, each fitted with a 1-ton "grab." After being picked up by the grab and raised from the barge, the coal is weighed, and discharged on to a travelling belt, which conveys it to the elevators. These elevators raise the coal to the top of the building—140 feet—for distribution to the bunkers by another set of belt conveyors, which discharge their load automatically into any one of a number of large bins. When brought by rail, the coal is tipped from the wagons, and then elevated and distributed as described. From the bunkers the coal is fed automatically to the furnaces. The tidal basin gives accommodation for six large barges, the storage capacity of the bunkers is 15,000 tons, and the plant can handle 240 tons of coal per hour. The daily consumption will eventually be about 800 tons.

Equally complete are the arrangements for removing the ashes. These are dropped from the hoppers into tip wagons, drawn by an electric locomotive to the water's edge, and there discharged into barges.

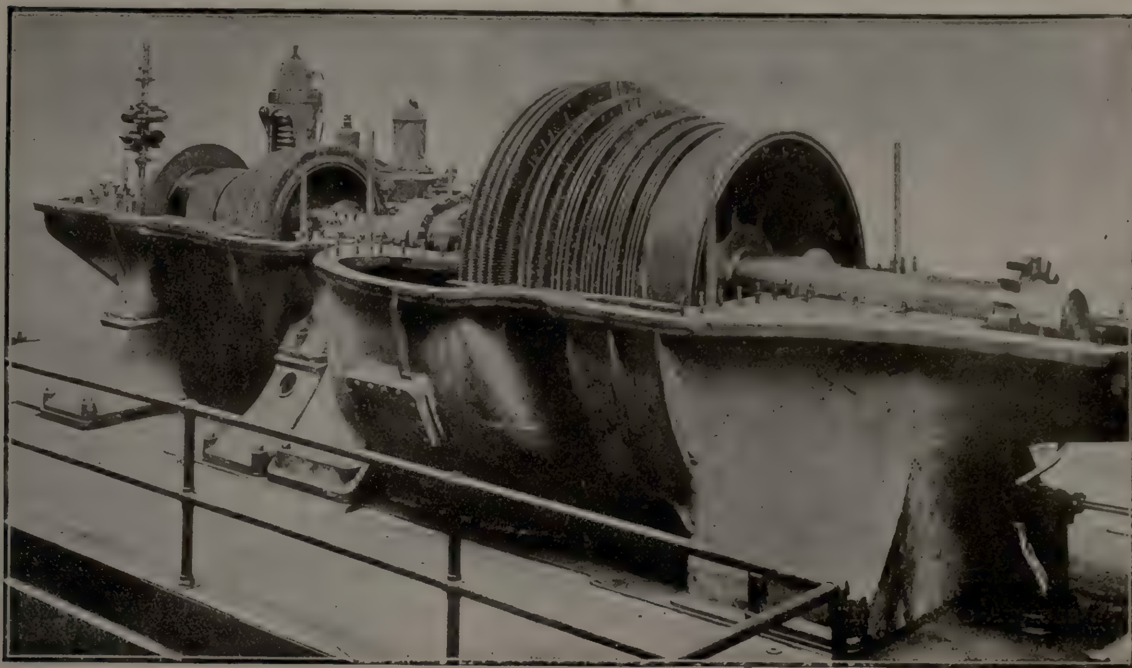
Automatic Stokers.

One side of the main building is occupied by sixty-four water-tube boilers, and space is reserved for sixteen more. The boilers are on two floors, with the coal bunkers above and the ash hoppers below; automatic chain grates feed their furnaces. In a chain grate the fire-bars consist of a series of short links assembled to form a wide flat chain of iron. The ends of this chain are joined, and it is carried on two revolving cylinders, like a belt over pulleys, and so arranged that its upper side travels slowly through the furnace. In this way the coal is conveyed from the bunker to the under-side of the boiler, consumed, and reduced to ashes by the time its journey is completed.

The Boilers.

Before entering the boilers the water passes through "*economisers*." These consist of a great number of tubes placed in the flues leading to the chimneys in order that the water may absorb heat from the waste gases.

The generating machinery consists of eight



ONE OF THE SIX PARSONS STEAM TURBINES INSTALLED AT THE LOTS ROAD POWER-STATION, CHELSEA.

Top of casing removed to show drum and blades. Each turbine has an output of 8,000 kilowatts at 1,000 r. p.m.

(Photo, Parsons Steam Turbine Company, Limited.)

steam turbines, each coupled to an alternating current dynamo, which combination is usually known as a "*turbo-alternator*."

The Generators.

Each machine is capable of producing, at normal load, 5,500 "*kilowatts*." We should remark here that the Board of Trade *unit*, the standard by which electricity is sold, is equal to 1 kilowatt for one hour. At the low price of one penny per unit the gross earnings per machine would be nearly £25 an hour. As a matter of fact, the output stated can be exceeded to the extent of 50 per cent. if required, and space is provided for two more sets of the same, and one of half the capacity. With the extra boilers the full equipment of the station will therefore consist of eighty boilers and eleven turbo-generators, with a total output of 57,700 kilowatts at normal load. Besides this, and the auxiliary machinery already referred to, there are four "exciter" sets for producing the direct current needed for energizing the field magnets of the alternators, for charging batteries, and for other purposes.

In conclusion we may, in imagination, follow the distribution of the current from the station. Generated at 11,000 volts, it is conducted through 285 miles of main cables insulated with paper, lead-sheathed, and drawn through earthenware conduits laid in concrete. There are twenty-three sub-stations at various points on the different railways. At each sub-station the high-tension alternating current is reduced from 10,000 to 370 volts, and then converted to a direct current at 600 volts for the electric locomotives, each of which is fitted with two 200 horse-power motors.

[NOTE.—*The writer begs to express his indebtedness to Garcke's "Manual of Electrical Undertakings" for many of the figures contained in this article.*]

UNDER SLUICES OF THE JHELUM WEIR, WITH NEEDLE DAMS DOWN.

THE GREAT IRRIGATION WORKS OF INDIA.

BY AN INDIAN IRRIGATION ENGINEER.

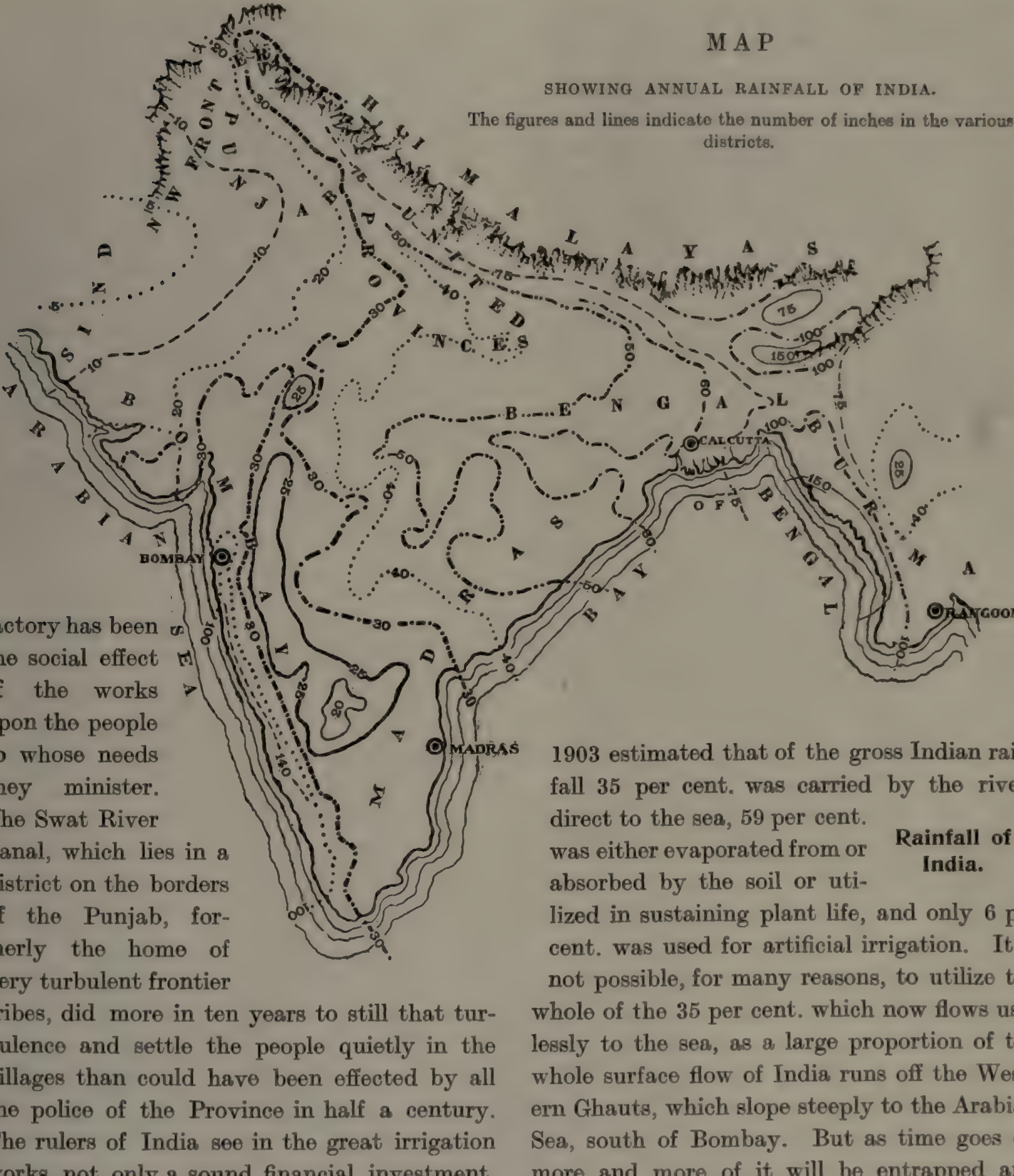
IN an address delivered on November 5, 1901, the President of the Institution of Civil Engineers said: "In England the great irrigation works of India are seldom heard of, and I cannot but think that the magnitude of some of them . . . is but little appreciated even by many members of our own profession."

It is not an uncommon error to suppose that all crops cultivated in India are irrigated artificially. The truth is that out of the average area—about 226,000,000 acres—of crops sown annually, 13,000,000 acres are irrigated, with great labour, from wells, 18,000,000 from canals, 8,000,000 from tanks, and 6,000,000 in various other ways. It should be added that of the total nearly 15,000,000 acres are watered by canals constructed entirely by the British Government, and one-third of the number by old native canals which have been improved, extended, and maintained by it. These Government works include thirty large, or "major," and seventy-three "minor" systems, and have an aggregate of about 45,000 miles of canals and distributaries.

Government Irrigation Works.

The cost has been heavy—some £30,000,000. Yet the net return averages about seven per cent. on the capital invested, which is satisfactory alike to the Government which laid out the money, and to the engineers who carried out the work. Even more satis-

Their Social Effect.



MAP

SHOWING ANNUAL RAINFALL OF INDIA.

The figures and lines indicate the number of inches in the various districts.

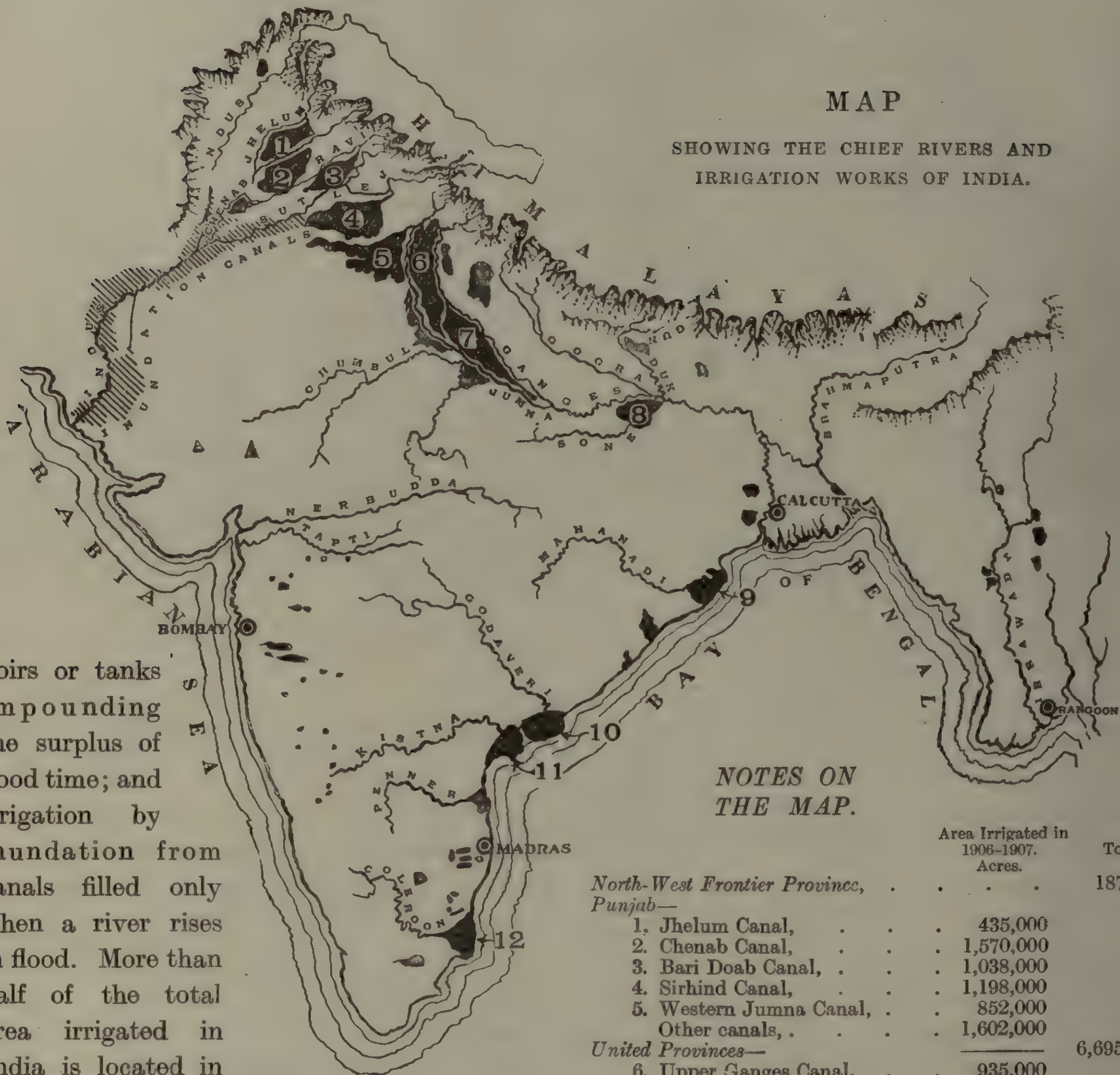
factory has been the social effect of the works upon the people to whose needs they minister. The Swat River Canal, which lies in a district on the borders of the Punjab, formerly the home of very turbulent frontier tribes, did more in ten years to still that turbulence and settle the people quietly in the villages than could have been effected by all the police of the Province in half a century. The rulers of India see in the great irrigation works, not only a sound financial investment, but, what is far more important, a political force and a powerful and beneficent means of convincing the agricultural classes—far the most numerous and important in the country—that Britain rules India primarily and emphatically for the good of the silent and persevering races which people it.

Rainfall of India.

The Indian Irrigation Commission of 1901–1903 estimated that of the gross Indian rainfall 35 per cent. was carried by the rivers direct to the sea, 59 per cent. was either evaporated from or absorbed by the soil or utilized in sustaining plant life, and only 6 per cent. was used for artificial irrigation. It is not possible, for many reasons, to utilize the whole of the 35 per cent. which now flows uselessly to the sea, as a large proportion of the whole surface flow of India runs off the Western Ghauts, which slope steeply to the Arabian Sea, south of Bombay. But as time goes on more and more of it will be entrapped and turned to good account.

Irrigated Areas.

For centuries before the British occupation irrigation had been practised in India, the same systems being used then as now—namely, perennial irrigation with water led through channels tapping a river far above the district watered, or from storage reser-



MAP

SHOWING THE CHIEF RIVERS AND IRRIGATION WORKS OF INDIA.

voirs or tanks impounding the surplus of flood time; and irrigation by inundation from canals filled only when a river rises in flood. More than half of the total area irrigated in India is located in the Punjab, and in the almost rainless tracts of Sind, where the rainfall varies from two to about five inches in the year, and where the waters of the Indus are led by a vast number of inundation canals over the thirsty lands. In the Punjab the five great rivers from which that country derives its name are utilized to water the "doabs" between the streams, on which the annual rainfall is said to range from 10 to 30 inches.

Coming to the schemes which have been carried out by modern engineers, we select first the great Chenab Canal, irrigating the tract between the Chenab and Ravi rivers of the Punjab. It is the largest and one of the most recent of Indian irrigation works—how

NOTES ON THE MAP.

	Area Irrigated in 1906-1907. Acres.	Total.
North-West Frontier Province, ...		187,000
Punjab—		
1. Jhelum Canal, ...	435,000	
2. Chenab Canal, ...	1,570,000	
3. Bari Doab Canal, ...	1,038,000	
4. Sirhind Canal, ...	1,198,000	
5. Western Jumna Canal, . .	852,000	
Other canals, ...	1,602,000	
	———	6,695,000
United Provinces—		
6. Upper Ganges Canal, . .	935,000	
7. Lower Ganges Canal, . .	924,000	
Other canals, ...	731,000	
	———	2,590,000
Bengal—		
8. Sone Canals, ...	564,000	
9. Orissa Canals, . . .	267,000	
Other canals, ...	72,000	
	———	903,000
Madras—		
10. Godaveri Canals, . . .	873,000	
11. Kistna Canals, . . .	664,000	
12. Cauvery Canals, . . .	983,000	
Other canals, ...	1,112,000	
	———	3,632,000
Bombay and Sind—		
Mainly inundation canals, and, to a small extent, reservoir systems, ...		3,702,000
Burma—		
Canals, ...		952,000
Other Provinces—		
Canals and Reservoirs, ...		41,000
Total in 1906–1907, . . .		18,702,000

HYDRAULIC WEIR SHUTTERS.

In the foreground is a self-acting shutter, which falls when the water rises to a certain height. It has hydraulic brakes at the back to break the shock as the gate rises. In the background is a front shutter, erect, holding up 10 feet of water.

large is not easily realized. The river Thames, when it overflows its banks and floods the adjacent country, swirling through bridges in a torrent and inundating some of the valley towns, carries about 10,000 cubic feet per second. The Chenab Canal, when doing its utmost, but so silently and peacefully as to look placid as compared with the rushing, hurrying Thames, carries 11,000 cubic feet per second—that is, more than the Thames in its angriest mood. The canal is 250 feet wide at the base, and when full has a depth of 11 feet. These are the dimensions at the head. From that point the channels taper down, spreading and branching here and there, until they are reduced to ditches perhaps only 18 inches or a foot wide at the base. The whole system comprises some 2,800 miles of channels, spreading, like the veins of a man's hand, over a tract of country little less than 4,650 square miles in extent—almost one-tenth the area of England, and half the cultivated area of Egypt.

The Chenab Canal.

This large area was all Crown waste land before the canal was made. A part, well wooded, with three or four kinds of jungle growth, bore a good crop of grass after a favourable rain; and on this nomadic tribes, the only inhabitants, pastured their cattle at certain times of the year. A small scrub and camel thorn covered some of the land. By far the larger portion was absolutely barren, a country of mirages which often deceived the engineers.

What the Canal has done.

Into such a region 400 miles of main canals and about 1,400 miles of distributaries now conduct the volume of water mentioned above. The main canals and the branches run on the main ridges, and the larger distributaries—some of considerable size, and passing 500 cubic feet a second—keep to the main watersheds. Two million acres of crops now grow annually on the lands which once were waste and sterile.

As the tract irrigated by the Chenab Canal was originally uninhabited, villages had to be formed and settlers introduced. The special colonization officer appointed had to survey his vast estate, and lay it out in villages and in holdings of convenient size. The system adopted was to divide the whole district into squares of 25 or 27 acres, each square having its individual supply of irrigation water.

HYDRAULIC WEIR: BOTH SHUTTERS DOWN.

Laying out the Chenab Canal System.

The laying out was a very arduous task. The survey parties had to work across vast stretches of totally uninhabited country, where the only source of water might be a brackish well 100 feet deep, and where no supplies of any kind could be obtained. It was often necessary to remain in the field throughout the hot season, when the tempera-

MAP OF THE CHENAB RIVER AND CANAL SYSTEM.

Escape reservoirs marked in solid black. The water is turned into these reservoirs when the volume is greater than the canals can carry.

ture rises to over 110 degrees Fahrenheit in the shade. It will be readily understood that under these circumstances high organization and much energy and determination were required from all concerned in the work.

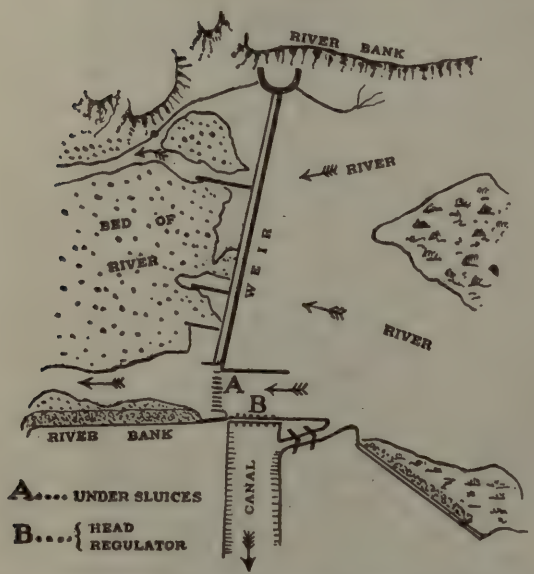
The survey completed, there followed the task of dividing the tract into villages of convenient size, averaging the gross area of 1,500 to 2,000 acres. The main principle was that the lands in each village should be irrigable from its own separate water-course. Each of these water-courses is supplied direct from a Government channel; so that all disputes that may arise are confined to the village itself, or lie between the villagers and the Government. Since the Chenab Canal was opened more than one and a half million acres of Crown land have been allotted to settlers, and a new population of more than 1,000,000, people has founded homesteads cultivated with the assistance of the canal waters.

The Chenab River usually remains fairly full until the middle or end of October, and suffices to irrigate the sowings of the winter crop. But later in the season the available discharge sometimes falls as low as 4,000 cubic feet per second, rising suddenly, when a freshet comes down, to 10,000 cubic feet. Arrangements therefore have to be made for distributing 4,000 feet one day and 10,000 the next.

Escape Reservoirs.

It has been found necessary to have canal telegraph lines run in all directions to control the distribution. This telegraph system is doubly useful when, after an unexpected fall of rain, there is a sudden reduction in the demand for water in the fields. One can easily appreciate the anxiety of an engineer who learns that the canal is bringing down 300 tons of water a second, and that he must dispose of it. If there be no escapes for the water, and the cultivators decline to run it on to their fields, he knows that the canal must burst its banks. On most Indian canals there are facilities for letting off surplus water, but in the case of the Chenab Canal the main courses are so far from the rivers that the provision of escapes

WASTE WEIR OF LAKE FIFE NEAR POONA, DOWN-STREAM VIEW. AUTOMATIC SLUICE GATES OPEN.



HEAD-WORKS OF THE SIRHIND CANAL ON THE SUTLEJ RIVER.

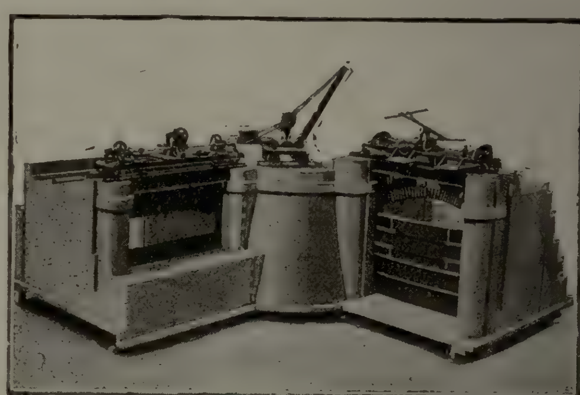
back into rivers at the points where they are needed is, in most cases, impossible. As an alternative, several depressions in the ground have been surrounded with earthen banks to form reservoirs, into which a portion of the discharge can be turned in an emergency. The water in them soon dries up, and leaves them free for further use. They are planted with trees, and form little forests as well as escape reservoirs.

The Chenab Weir.

At the head-works of the Chenab Canal the river is about $3\frac{1}{2}$ miles broad—broader than is necessary for the discharge of the floods. In the bed of the river has been built a weir to hold up the water as much as 12 feet above low-water level. The weir itself is only 4,000 feet long, but over it the whole discharge is compelled to pass by a system of training walls. Measured in the direction of the stream it is 250 feet wide. The crest is of masonry 8 feet high and broad, with its base generally but 4 feet below the original summer level of the river. Forty feet up-stream of this wall a masonry curtain wall has been sunk 20 feet into the bed, to prevent undermining. The weir is divided by masonry piers into eight bays, each 500 feet wide. Between the piers, on the crest of the wall, are rows of vertical iron shutters, the construction and action of which may be taken as typical of all those now generally employed on Indian weirs. The shutters, 6 feet high, 3 feet broad, and made of $\frac{3}{16}$-inch steel plating stiffened with angle iron, stand side by side in a continuous row between the piers. Heavy double hinge blocks placed between two adjacent gates are bolted down to the masonry. Three feet up-stream of each shutter

Weir Shutters.

a tie rod is hinged to the crest of the weir ; its other end slides in a groove on the nearer face of the gate, and is fitted with a hook which falls automatically into a slot when the gate is erect and is caught by a trigger on the down-stream face of the gate. To let the shutter fall, this trigger is knocked to one side by hand or mechanically, and the shutter is laid flat by the pressure of the water behind. For raising the shutter, a crane, running along the crest of the weir behind the shutters, is provided. It is not often needed, however, as three men can easily lift a shutter in three



ONE BAY OF THE HEAD REGULATOR (TO LEFT) AND ONE BAY OF THE HEAD SLUICES (TO RIGHT) OF THE SIRHIND CANAL.

The regulator has a masonry sill to keep out of the canal the heavy silt which is carried at the bottom of the stream, and formerly caused a great deal of trouble. Each sluice has three iron gates—an upper, a middle, and a lower—working in separate contiguous grooves, so that the water may be let through at any level required.

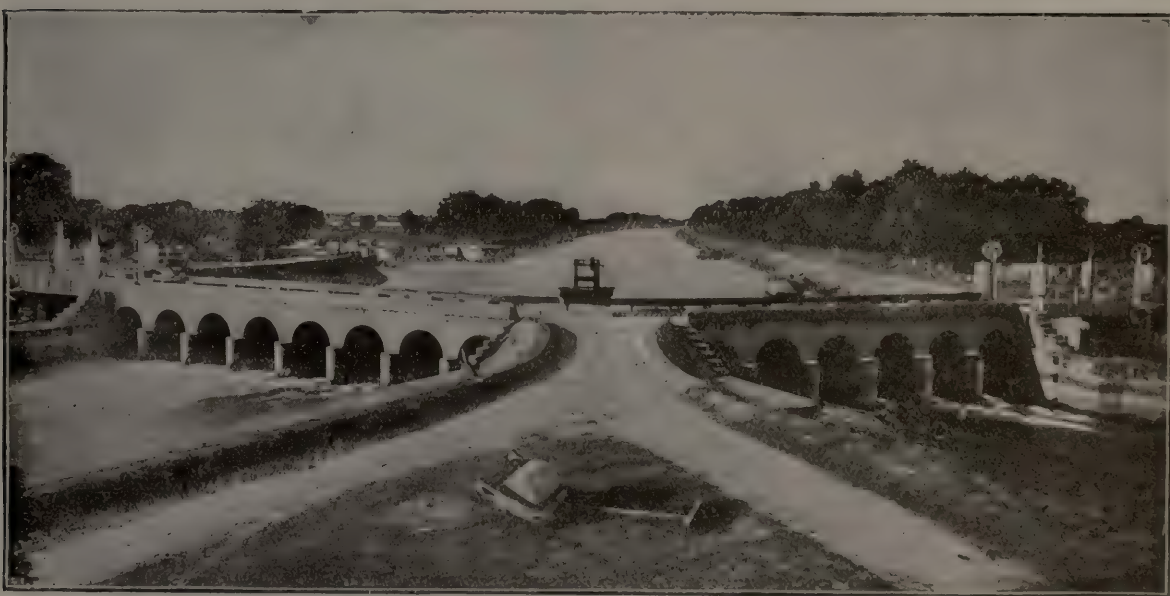
HEAD BUNDS, OR TEMPORARY DAM, OF THE GANGES CANAL, LOOKING UP-STREAM.

The construction of the bunds is described in the letterpress.

minutes by hand against 2½ to 3 feet of water. Only when the last two or three have to be raised, and the pressure of the water has increased greatly, are mechanical means necessary.

The Chenab Canal system cost £2,000,000; the gross revenue derived from it is about £500,000 annually; the value of crops raised on the land watered by it was in 1907 over £2,500,000. These figures show conclusively whether the expenditure has justified itself.

The natives of India still believe, or profess



GOPULPUR WORKS, SHOWING BRANCHING AND JUNCTION OF THE GANGES AND LOWER GANGES CANAL.

to believe, that when the British Government is about to commence new work, especially if it be a work of some magnitude, that the heads of human victims are buried below the foundations, the heads having been collected beforehand by emissaries of the Government or the engineers. On one occasion there was a scare of this kind in Dinapore, near Patna, at the inception of a certain scheme. The natives gravely asserted that an order had gone forth for human heads, and that the soldiers of the neighbouring garrison were killing men to obtain the necessary material. They were so convinced of the truth of the story as not to dare to stir out at night unless two or three went together. Such scares as this have occurred more than once, and may serve as examples of some of the minor difficulties with which the engineer has to contend.

Native Superstition.

The Bari Doab Canal, in the Punjab, which we will consider next, was one of the first of the large irrigation works undertaken by British engineers. It waters the tract lying between the Bias and the Ravi—the cradle of the Sikh nation, in which lies the holy city of Umritsir. The works were commenced in 1850, and now irrigate over 1,000,000 acres. During the early period of the annexation of the Punjab large bodies of disbanded Sikh soldiers constituted a possible source of trouble to the authorities, and to give them employment and permanent homes this canal was projected and completed in part by 1859. At that time the canal had no proper head-works, and the control of the water was inefficient. So permanent head-works were commenced during 1868, when a weir was built across the river Ravi, which supplies the canal. At the site of the off-take the Ravi has a bed of boulders of coarse shingle and a fall of about 20 feet in the mile. In the dry season the river winds from side to side of the broad bed, a limpid, shallow, swift current of little width. When the snows melt and the monsoon rains fall on the hills, it becomes an angry, turbid flood, by which the heavy boulders in the bed are borne along.

The Bari Doab Canal.

SLUICES OF THE BARI DOAB CANAL, UP-STREAM SIDE.

Across this river the engineers built a weir rising only 3 feet above the bed. High floods rise about 10 feet over the crest. The wall is built of boulders set in good mortar.

The engineers had to protect the piers and under sluices from the large stones swept down by the current by sheathing them in sheets of iron.

A Beautiful Spot.

Owing to the lack of that experience which has been gained during the last half century, the engineers made the mistake of placing the head of the Bari Doab Canal too far up the river. The results have been costly, but beautiful. In the first twelve miles of its course the canal drops more than 200 feet by a series of cascades and rapids, and winds between well-wooded banks, protected by stone revetting at curves, in a comparatively shallow stream. The velocity of the current is high, and the water sparkles brightly in the sun. It is as pretty a piece of canal scenery as India can show.

The Ganges Canal.

The river Ganges, which has a course of more than 1,500 miles, and a catchment basin extending over an area more than seven times the size of England, is bridled at two points to irrigate the fields of the United Provinces. The two systems have quite separate heads, but meet at a certain point. Together they include 6,500 miles of channels, and irrigate, in some years, more than 2,000,000 acres of crops.

Building Temporary Dams.

The head of the Ganges Canal is at Hurdwar, a very beautiful place, and one of the most holy spots on the most sacred of Indian rivers. The canal works had to be carried out in such a manner as not to affect the sacred bathing places of the Hindus, although a channel passing these spots had to supply the canal. In this very picturesque channel several masonry weirs and escapes have been built to regulate the stream. More interesting is the temporary dam constructed during the dry season to force the waters of the parent stream to flow down the channel. The first operation in the making of the dam is to fix a 14-inch rope across the river, and to prop it up at intervals so that it hangs in festoons. Triangular cribs are made on the bank out of poles bound strongly together. A barge picks up one of the cribs by means of a derrick hanging over the stern, and is drawn with the help of pulleys running on the main rope into the required position on the line of the dam. Then the crib is lowered gradually on to the bed of the river, boulders being dropped into it as it descends, so that by the time it is seated its weight suffices to keep it steady. It is then lashed to its neighbour, and weighted with more boulders. This operation is repeated until a line of cribs extends right across the river. All this is done in a stream 8 or 10 feet deep in places, and moving perhaps 12 feet per second. Next, the dam is raised by boulders dropped uniformly

NARORA WEIR, LOWER GANGES CANAL. WATER PASSING OVER WEIR.

THE SOLANI AQUEDUCT, WHICH CARRIES THE GANGES CANAL OVER THE SOLANI RIVER.
It has 15 arches of 50 feet span, is 195 feet broad, and passes a stream of water 172 feet across and 9 feet deep.

into the cribs till its top is at the level of the water which, during construction, had been flowing over it.

The boulder dam when complete is, of course, very leaky. This is remedied partially by sinking grass mattresses on the up-stream face, and throwing on to them boulders, shingle, and soil until an almost watertight embankment has been formed, to direct the river into the channel feeding the canal. It may seem strange that so primitive a structure should be a mainstay of the prosperity of a large tract of country. But so it is, and the canal has worked effectively for half a century.

The Solani Aqueduct.

The Ganges Canal has a maximum capacity of 7,000 cubic feet a second. This great volume of water is carried by level crossings through some rivers, over others, and in aqueducts, the most notable of which—that over the Solani—has fifteen arches of 50-foot span, is 195 feet broad, and gives passage to a stream 172 feet broad and 9 feet deep. We may notice that in some cases a river is led over a canal; for instance, a river 400 feet broad and 9 feet deep in flood crosses the Sirhind Canal at a height of 24 feet.

The Formation of Deltas.

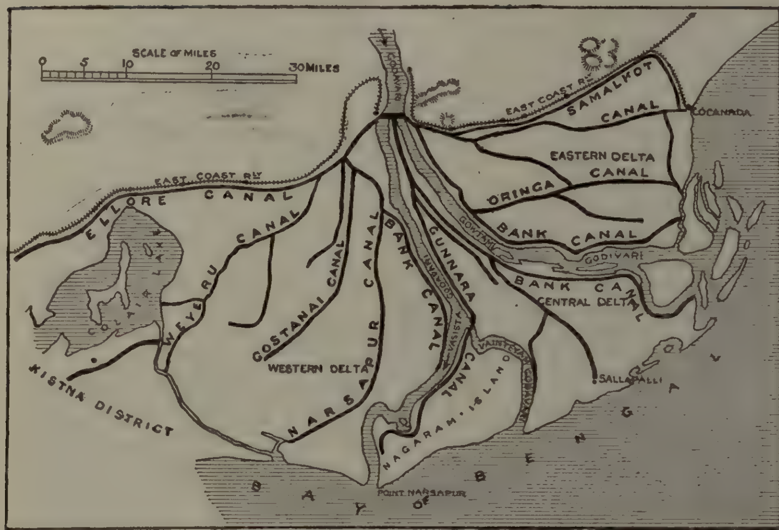
On the eastern coast the rivers, as they approach the sea, become deltaic. In their lower reaches the reduced velocity of the stream causes the matter eroded in swifter upper reaches to be deposited, and so raises the bed until the water overflows. The silt is then deposited on the land, the general level of which rises until the water is once more confined. This process is repeated along the banks and at the river's mouth until a great fan-shaped body of land has been pushed out into the sea, traversed by the several branches into which the river has divided. These branches run along the ridges of the country, a condition of affairs which is ideal for irrigation.

In the delta of the Godaveri a weir spans the river at Dowlaishweran, holds up the level of the water, and compels the stream to flow into three main canals. These supply many branch canals, which feed many more dis-

LAKE WHITING, AT BHATGUR, NEAR POONA.

The Bhatgur Dam, shown here, impounds over 5,000,000,000 cubic feet of water.

LAKE FIFE, NEAR POONA.



MAP OF THE GODAVERI DELTA CANALS.

tributaries, and they in their turn supply thousands of villages with the water which matures the crops. The canals cost somewhat less than a million sterling, and irrigate from 700,000 to 900,000 acres. They owe their inception to the genius of Sir Arthur Cotton. Commenced in 1864, they have brought wealth to the people of the delta.

Godaveri Delta Canal System.

One of the earliest methods of irrigation in India was from surface tanks, which are found in nearly all parts, but are most numerous in Madras, where they number 33,000, and water millions of acres of rice crops. These tanks vary in area from a few acres to nine or ten square miles.

Tanks.

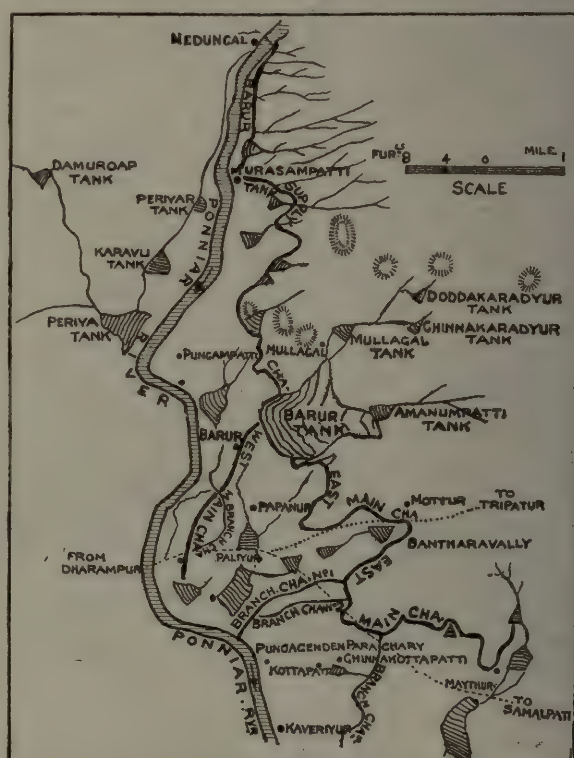
More individually important, but really in the same class, are the reservoir systems, which occur chiefly in Bombay. Nearly all the tanks and many of the reservoirs are formed by earthen embankments thrown across local drainages, but in some cases are fed from intermittent streams, storing the surplus water of one period for use at a later season. The larger works have been constructed by the British Government. Some have masonry dams varying in height from 100 to 162 feet, built across a gorge to impound the water.

Reservoirs.

The most interesting of these reservoir systems is that emanating from the Periyar River, which flows down the western slope of the Western Ghauts to the Indian Ocean. On this slope there is no irrigable land, whereas on the eastern slope there is plenty. The Periyar system taps the river, stores its water in a reservoir on the western side of the hills, and leads it through a tunnel right across the watershed into the thirsty plains of Madura in Southern Madras.

Periyar River System.

The most interesting feature of this undertaking is the concrete dam, 1,241 feet long and



MAP OF THE BARUR TANK SYSTEM IN MADRAS.

The tanks are shown as shaded areas.

THE MARIKANAVE DAM, IN MYSORE.

It is able to impound a lake of 40,000,000,000 cubic feet, with a greatest depth of 130 feet. Length of dam, 1,350 feet.

155 feet high, built across a narrow ravine at a point where the Periyar River passes between two hills. The reservoir formed by it will contain 13,300,000,000 cubic feet of water, about half of which is available for irrigation. This proportion is drawn off through a Stoney sluice gate, and a tunnel over a mile long cut through the solid rock, into the channel of the Vaigai River, down which it flows 86 miles to the plains, where it is distributed by means of a weir and an ordinary system of canals.

The Periyar Dam and Tunnel.

In the Bombay Presidency are many reservoirs. The two most important are Lake Whiting and Lake Fife. The first of these, formed by the Bhatgur dam, contains a gross volume of 5,313,000,000 cubic feet of water, of which 3,953,000,000 can be utilized. The water is drawn off below the dam, and flows down the rocky bed of the Nira to a weir which diverts it into a system of canals.

Lake Whiting.

The Bhatgur dam, of masonry and concrete, is 3,020 feet long, 127 feet high (maximum), and 76 feet wide (maximum) at the base. The catchment area of the basin above the dam is 128 square miles, and the annual rainfall on this area varies from 250 inches in the hills to 40 inches at the dam site. Heavy rains cause floods of 50,000 cubic feet per second, and to pass this enormous quantity the engineers have constructed two waste weirs with a clear waterway of 810 feet, over which the water passes eight feet deep—a truly impressive waterfall.

The waste weir of Lake Fife is even larger than those of Lake Whiting, for it is able to pass 75,000 cubic feet per second. On its crest, 1,200 feet long, are eighty-eight gates, each 10 feet wide and 8 feet high, working on a unique principle. The gates are in pairs, the heavier of the pair opening downwards, the lighter upwards. When the heavy one rises the light one falls by its own weight, while, on the other hand, the descent of the heavy gate pulls up the other. The gates open and close automatically, through the operation of a counterweight, which is affected by changes in the level of the water passing through the weir. This ingenious arrangement dispenses with the necessity for working the gates by hand when a flood occurs.

Lake Fife.

The Marikanave reservoir in Mysore is a proof of the interest taken by the native ruler of an independent State in works of improvement. It was due to the energy of the late Sir Sheshadri Iyer, and to the warm support of her Highness the Maharani, that this great enterprise was carried out.

Marikanave Reservoir and Dam.

The reservoir water is impounded by a dam built across a gorge about 1,200 feet wide at the crest of the dam, which is 142 feet above the river bed, and from the foundations has a maximum height of 167 feet. The reservoir will store a depth of 130 feet near the dam, and the water will spread over an area of 34 square miles. The maximum amount that can be stored is calculated at 40,000,000,000 cubic feet, but such a quantity would collect only after unprecedented floods. The reason why the ultimate capacity is so greatly in excess of the ordinary volume (10,000,000,000 cubic feet) that will be impounded is interesting. It was proposed originally to provide a capacity of 20,000,000,000 cubic feet; but as a cyclonic rainfall would fill the reservoir and require a large escape to save the dam, it was found to be cheaper to increase the height of the dam and enable the reservoir tc absorb the storm waters instead of allowing them to pass forward down the river.

The life of an irrigation engineer in India is often a very lonely one, especially on some of the Punjab systems, where vast tracts of land have been reclaimed quite recently from almost absolute desert. There, for weeks, perhaps months, at a stretch he may never see another European, and have to subsist on very simple fare. The recompense of such a life is that it brings him into very intimate contact with the agriculturist and his daily toil, his patient perseverance, his generosity to friends in distress. In short, he sees a great deal of the best side of the Indian "ryot." But it is when famine stalks the land that the engineer reaps his best reward. One engineer, who has now retired from the Indian service, spent some years of his Indian life on the construction of a system lying south of the Ganges. He saw it commenced; he saw it finished. Much later, he was responsible for the administration of that system when it was irrigating some 500,000 acres of crops in the year. At that time, also, he was responsible to some extent for the works in another district north of the Ganges, where there were no canals. It was his duty to visit both. A time of scarcity and of famine came. The rainfall in the "khareef" season—the season when the rice is grown—failed, and there was difficulty in even raising the seedlings of the crop which are transplanted subsequently into the fields. The ground was too hard to plough. Under the irrigation from the canals south of the Ganges, the crop was raised, transplanted, and watered. But this not without difficulty, so great was the demand, so hasty the people sometimes. North of the Ganges, where there were no canals, only a

The Irrigation Engineer's Life.

A Contrast.

A GANG OF PROFESSIONAL STONE CARRIERS.

Their wages are so low (10 to 16 cents a day) that mechanical handling plants cannot compete here with manual labour.

portion of the fields could be planted at all. A few months later this engineer had to ride over those lands north of the river to try to find work for the people. For more than 100 miles he passed through fields which should mostly have been bearing rice crops—as in a sense many of them were. In thousands of fields there was a plant here and there—perhaps two or three to the square yard—bearing an ear. In that ear there might be four or five grains, instead of forty. A great many of the fields were given over to the cattle as

grazing ground. Straight from the trip this official crossed to the south of the river. He found the whole area which had been irrigated bright with the brilliant shining green of a flourishing crop. A little later on, when the harvest was carried to the "kurrians" — the threshing floors—he once more visited both districts. On the north of the Ganges could be seen only little baskets of grain on the threshing floors; on the south, great heaps of golden rice. In the one district the people were crowding on to the relief works; in the other there was no need of them. That year the price of grain was high; the people in the irrigated tract sold their surplus at famine prices, and it is estimated that the extra money they realized more than sufficed to pay their water rates for seven years. Since that time a canal has been designed, and is now nearing completion, to irrigate a part of that tract north of the Ganges which suffered. Who shall say that the engineer, who sees a canal constructed and then sees its results, does not receive a reward which few others can enjoy so thoroughly as he?

Plenty and Famine.

It may be asked, why, if irrigation works can produce these results, canals are not so extended as to prevent famine altogether. Because unlimited expenditure would not prevent famines. Irrigation is not physically possible in all parts which may be struck by famine. There never was a time when, taking India as a whole, the food supply of the continent was insufficient to feed the people. The difficulty has always been to deliver the food to the people, and to do it without demoralizing them. It is true that the irrigation works of a particular district liable to famine will relieve the tract which is actually irrigated, and also a zone lying for some distance beyond the borders of that tract. But where irrigation cannot be practised the importation of grain is the only means of relief. An acre of food grain will feed from two and a half to three people for one year; on this basis it has been calculated that the existing irriga-

The Distribution of Food.

VIEW OF THE COUNTRY SUBMERGED BY THE WATER IMPOUNDED BY THE MARIKANAVE DAM.

tion works are capable of providing food for one-fifth of the population of the provinces in which they lie.

The gross value of the crops raised on the irrigated area in India is about £40,000,000 annually. It must not, however, be assumed that this out-turn is entirely due to the works. The irrigation assures, improves, and increases the produce of the fields; without irrigation there would, in most tracts, be a crop. It is in famine years only that water prevents the entire loss of the harvest.

Value of Irrigated Crops.

GENERAL VIEW OF THE MYAPORE REGULATOR AND ESCAPE AT THE HEAD OF THE GANGES CANAL.

THE STATUE OF LIBERTY, ON BEDLOE'S ISLAND, AT THE ENTRANCE TO NEW YORK HARBOUR.

BUILDING THE STATUE OF LIBERTY.

An account of the Erection of the Colossal Figure on Bedloe's Island in New York Harbour.

STANDING on Bedloe's Island, a small islet in New York Bay, is the great Statue of Liberty, the largest monument of its kind, the creation and erection of which called for no mean engineering skill. This colossal female figure, whose torch towers over 300 feet into the air, is an imposing object as seen from steamships coming up the harbour, from ferry-boat and bridge and river, and from the encircling cities and hills and plains of New York and New Jersey.

Inception of the Scheme.

Although the object of this article is mainly to describe how this giant among statues was built in France, transported over 2,000 miles across the Atlantic, and erected in New York Harbour, some reference to its inception, and the reason why it adorns its present site, will not be inappropriate. It is the work of the eminent French sculptor M. Auguste Bartholdi, who obtained his idea of creating such a figure and presenting it to the American nation from his friend M. Laboulaye.

A Splendid Gift from France.

The object of artist and friend was to produce something that would be a fitting gift, and commemorative of the long-established goodwill between the two nations. An influential committee was formed, and so far back as 1874 the French public were asked to subscribe to a fund to meet the cost of building the statue. Various festivities were held throughout the country with a view to collecting the necessary money, and in that year the work was commenced. Two years later a portion of the monument, the hand

bearing the torch, was completed in Paris, and sent to America, where it was exhibited in Philadelphia, and subsequently in New York. An Act of Congress accepting the statue as a gift from the French people, and setting apart Bedloe's Island as a suitable place for its reception, was passed in 1877. The following year another portion of the figure, the head, was finished, and exhibited at the Paris Exposition.

MAKING FULL-SIZED PLASTER MODELS OF PARTS OF THE STATUE.

In the background is seen the complete small-scale study model, from which the larger-scale models were successively produced. On the left, three workmen are busy modelling one of Liberty's fingers.

Interesting Figures.

The statue was completed in 1883, and in the same year the building of the great pedestal on which it stands was begun. Some idea of the colossal dimensions of both figure and pedestal may be gained from the following table of the principal dimensions :—

	Ft.	In.
Total height of statue	151	1
Foundation of pedestal to torch	305	6
Heel to top of head	111	5
Length of hand	16	5
Index finger	8	0
Circumference at second joint	7	6
Size of finger nail .... 13 by 10 in.		
Head from chin to cranium	17	3
Length of nose	4	6
Right arm (length)	42	0
Right arm (greatest thickness)	12	0
Thickness of waist	35	0
Height of pedestal	89	0
Square sides at base (each)	62	0
Square sides at top (each)	40	0
Height of foundation	65	0
Square sides at bottom	91	0
Square sides at top	66	7

The size of the statue is far greater than any other in the world, the celebrated Colossus of Rhodes having been but some 105 feet in height, and that of Nero, by Zenadore, about 118 feet. The designing and modelling of the figure entailed a vast amount of labour; indeed, it occupied sixty men ten years. It is ceeded to construct models or moulds upon which the copper casing, or envelope, could be shaped. This outer covering of copper, it may be added, is only about $\frac{3}{32}$ of an inch in thickness, and necessitated elaborate precautions to keep the outlines and corners rigid and in shape.

THE MODEL OF THE LEFT HAND OF THE STATUE AND OF PART OF THE DRAPERY.

thought that Bartholdi modelled the figure from his mother. First of all, he prepared a study model, seven feet high. This was enlarged to four times its original size. This, in turn, was very carefully studied and remodelled, and then divided into a great number of sections, over three hundred in all, each of which was marked with a distinguishing figure or number. The exact form of the statue having been settled, the sculptor pro-

How the Model was prepared.

All of the sections referred to above were again enlarged four times. They were made with the greatest geometrical precision by means of a number of wires and leads attached to the pieces, from which dimensions were taken off with compasses, some of the sections requiring as many as 9,000 separate measurements. Plaster moulds of these sections were then prepared, and as these were completed carpenters built wooden models of

Moulding the Pieces.

them. Upon these the copper was moulded by blows from mallets assisted by levers, the fine finishing touch being given with small hammers or rammers.

This copper shell, owing to its thinness, lacked rigidity, and it was necessary to increase the stiffness of every piece, particularly

BEATING PART OF THE COPPER SHELL OF THE STATUE INTO SHAPE ON WOODEN MOULDS.

those of large size, by means of iron bars secured to the interior surface. These bars

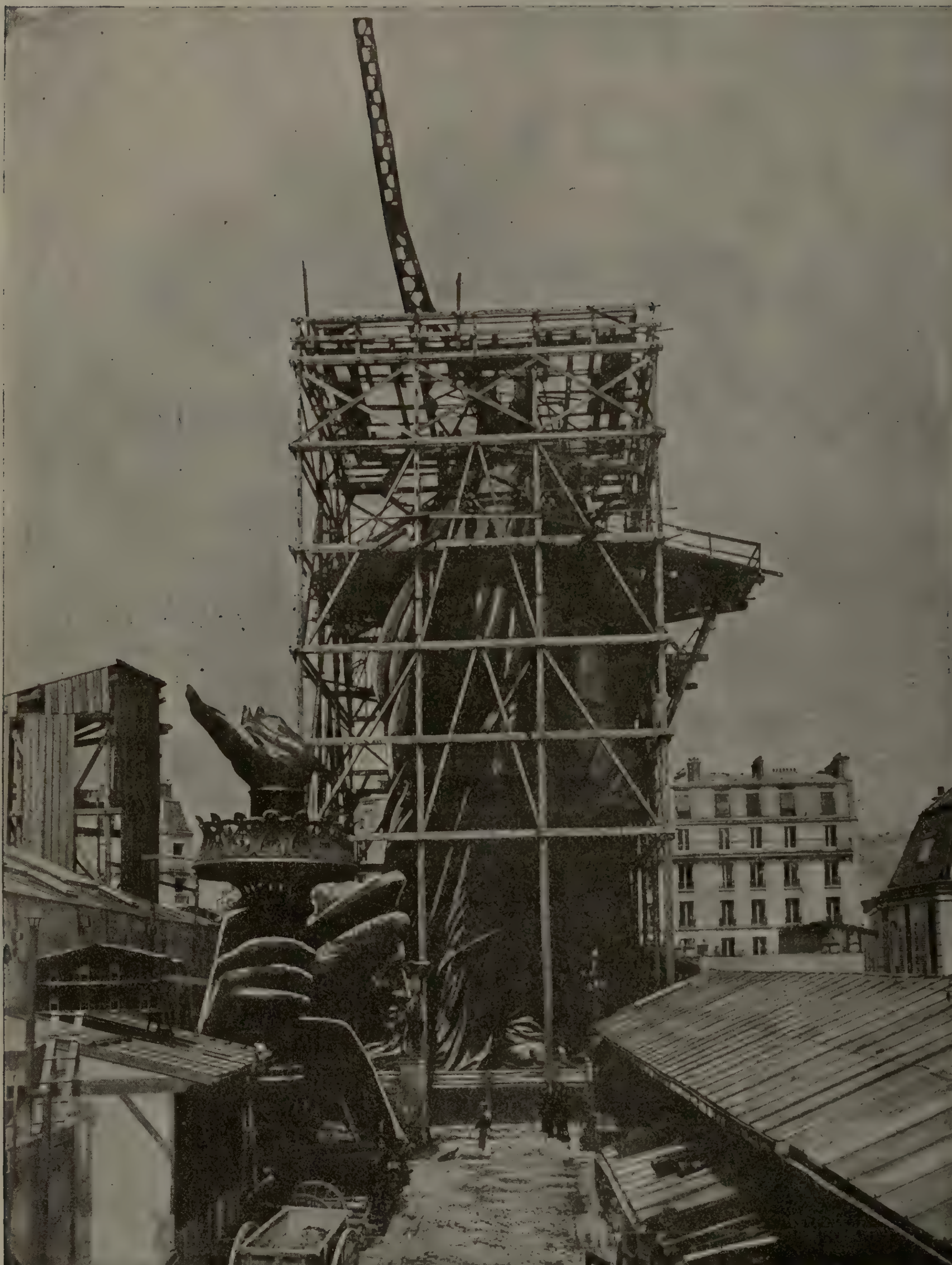
Internal Stiffening Bars.

were so bent as to conform closely to the curves in the copper, to which they were fastened by copper bands; their ends were riveted to the shell, and were so disposed and united to each other as to form a most intricate network of bracing, covering and strengthening the entire statue.

The statue was made in no less than 350 separate parts. It was essential that these should be assembled together in the workshop to see that they fitted exactly.

The Supporting Frame.

A huge iron frame, designed by M. Eiffel, the builder of the Eiffel Tower, was made, and to this the numerous sections were fitted. It consisted of four massive angle-iron corner posts, united by horizontal angle pieces, dividing it into panels, which were strengthened by steel struts and braces, arranged diagonally, and possessing side extensions to approach more closely to the contour of the figure. The smaller frames supporting the head and the extended arm of the figure were of lighter construction than, but similar to, those of the main frame. The shell, or monument, is, of course, bolted to this iron framework. By assembling the



TRIAL ERECTION OF THE PARTS AT PARIS.

On the left of the picture are the hand and torch which form the loftiest points of the Statue. Observe the iron framework for supporting the right arm.

pieces together the engineers were enabled to pierce the necessary holes for the rivets at the edges where they overlapped.

THE LEFT FOOT AND PART OF THE DRAPERY OF THE STATUE.

When the statue was taken down in France the pieces were packed in frames of wood, to prevent damage by bending, and brought over to New York in a French war vessel. While the sculptor and his assistant had been busy in Paris the Americans had commenced operations at Bedloe's Island by preparing a suitable base, and erecting a handsome pedestal to carry the monument. Naturally, it was desired that the foundation should be a particularly solid one. It is, in fact, a solid piece of concrete, one of the largest monoliths in the world, 65 feet high, 91 feet square at the base, and 66 feet 7 inches square at the top. It rests upon a soil composed of stiff clay, gravel, and boulders. Upon this foundation was built the pedestal, a particularly handsome construction, towering 89 feet in height.

Foundations.

The erection of the monument was a very tedious and slow process. It meant work at great heights, and in so confined a space as to prevent the employment of a large number of men. It was most essential that the riveting should be done very carefully; otherwise there would be unseemly lines. The pieces were temporarily stored in a great shed at the foot of the pedestal, and lifted as required by a derrick on to a huge platform built round the top of the pedestal. Here the protecting cover of wood was removed, and the piece was raised by rope and tackle into its proper position, and held in place until enough rivets or small temporary bolts had been inserted to secure it. All the rivets were then driven and the section bolted to the frame, or rather to the supporting bars. The outer heads of the rivets were of copper and countersunk.

Erection of the Statue.

In this manner the shell was carried upward piece by piece, until the monument stood complete. No part of the ironwork is in direct contact with the copper, a thorough insulation being obtained by shellacking the adjoining surfaces and interposing a strip of asbestos.

This was necessary to prevent the corrosion which would otherwise be caused by the action of electricity induced by the damp salt air.

This gigantic statue is justly admired for its majestic proportions and the benevolent calm of the countenance. The pedestal, too, is quite an artistic creation. At its summit is a balcony, 3 feet 7 inches wide in the clear, running round its four sides. It has also a loggia 26 feet 7 inches high. Around the base is a terrace, 15 feet 6 inches wide, to which a staircase leads. Shields bearing the coat of arms of the several states of the American Republic are arranged round the base.

The Pedestal.

The statue alone weighs 100 tons, its composition being three-fifths iron and two-fifths copper. Its cost is estimated at £50,000. To this sum we must add £70,000 for the base and pedestal, making £120,000 in all. Both pedestal and monument can be ascended, and the trip from the Battery to the island for a view of New York from the pedestal balcony or from the torch is regarded as one of the things that should be done by every visitor to New York. The torch, at the extreme height of the extended arm, is reached by a staircase in the monument. Fifteen people can easily find accommodation around the torch balcony. Just above this balcony is an electric light, which illuminates the statue every night.

October 28, 1886, was the day fixed for the unveiling of the statue, or, to speak more correctly, for its ceremonial inauguration. A grand military and civil procession took place on shore. Then the President of the Republic and the most distinguished personages boarded thirty-seven steamers for the island. After a prayer and some music, M. de Lesseps delivered an address. This was followed by an address by Senator Ewarts announcing the presentation of the statue by France to the United States. The face, which had been shrouded by tricolour flags, was then unveiled amid the terrific din of cannon, steam whistles, and hooters. President Cleveland then formally accepted the monument, and the ceremony closed with the singing of the Old Hundredth.

The Inauguration Ceremony.

A BESSEMER CONVERTER

ORE HANDLING PLANT MOVING ORE FROM SHIP TO STOCK-PILE.

Two Hulett conveyor bridges are shown in this picture. The nearer one has its front cantilever raised; the other has just dumped a load from its 5-ton bucket.

REMARKABLE MACHINERY USED IN THE MANUFACTURE OF IRON AND STEEL.

BY FRED. G. SMITH.

THE number and complexity of the mechanisms to be found in a modern steel works is a surprise to most people who visit such a place for the first time. The old-fashioned methods of handling material have been superseded by machinery. The dominant word in the steel works of to-day is speed. Managers for ever cry out, "Faster, faster," and the engineer racks his brains to respond. A glance at the high-speed and almost automatic machinery to be seen in the steel works of to-day convinces one that the engineer has replied most effectively. Some of the large works turn out as much as 2,000,000 tons a year, and the handling of so vast an amount of material through the works demands some special types of machines.

Steel-Works' Machinery.

In the United States it has been found necessary to transport the iron ore across the Great Lakes to the steel manufacturing districts of Michigan and Pennsylvania; and as navigation on the Lakes is suspended in the winter months, it becomes necessary to create large ore reserves during the open season. This stocking of material near the quay must be carried out very expeditiously, so that the boats may be delayed as little as possible, and so enabled to make a maximum

The Hulett Ore Unloader.

TWO HULETT AUTOMATIC ORE UNLOADERS AT WORK.

The walking beam of the nearer one has been run back from the ship, and the mast has been raised. The unloader in the background is seen in the act of dipping its mast into the ship's hold.

number of voyages while the Lakes are open to navigation. A consequence of quick unloading is naturally cheaper freight rates, owing to the great saving of labour as well as of time effected by the marvellous unloading and stacking machines employed. One of the most remarkable devices used for the rapid disembarkation of iron ore is the Hulett unloader. This machine consists primarily of two parallel girders mounted upon a structure wide enough to span four lines of railway. The girders are at right angles to the quay. The whole structure is supported by wheels, and can be moved along the quay into the position required for unloading the boat. Travelling upon the parallel girders is a trolley carrying a long rocking beam pivoted at the centre. From the end of this beam hangs a two-jawed automatic bucket, which is arranged to be lowered on to the ore with its two halves apart or open. As soon as the closing mechanism is put into operation, the jaws move together, biting into the pile of ore. Not a small bite, however, as it is nothing extraordinary for one of these buckets to bring up ten tons of ore. The action of the machine when unloading a boat is briefly as follows: The trolley with the walking-beam travels forward along the girders out over the boat, until the mast carrying the bucket at its lower end is above one of the hatches. The mast then descends until the bucket rests upon the iron ore, when the bucket is closed and the mast raised. The trolley then moves back; the bucket comes over a large bin built into the superstructure, opens its jaws, and discharges the ore. This cycle of operations is repeated until the boat has been emptied.

From the bin the ore is dumped through

LEG AND BUCKET OF HULETT UNLOADER AT WORK IN THE HOLD OF A MODERN ORE-CARRYING VESSEL.

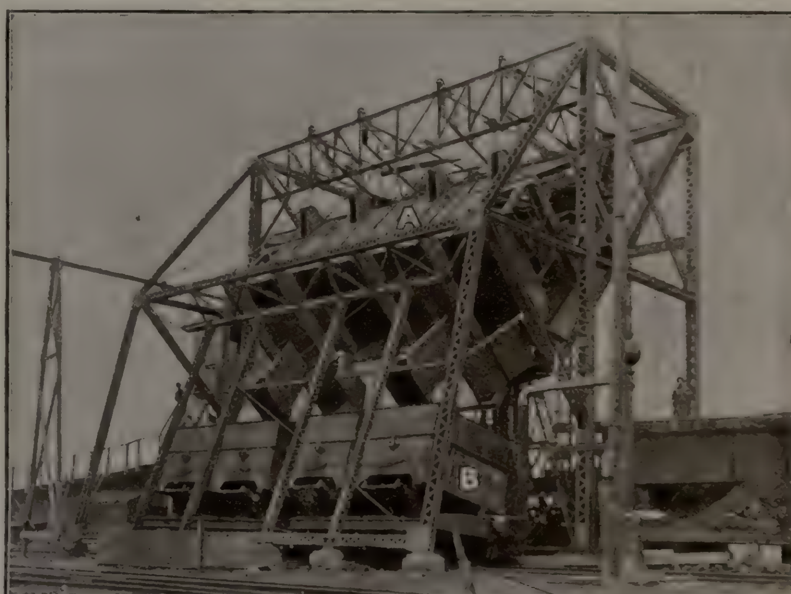
traps in the bottom into main-line cars on the tracks underneath, and hauled away by the yard locomotive. In cases where the ore has to be stacked in a pile immediately to the rear of the quay, it is discharged into a second conveyor built on to the unloader, run out over the stock pile, and dumped.

Apart from their huge capacity, these machines are remarkable for the method of their control. The operator is carried in the steel mast just above the bucket, and descends with it into the boat. He is therefore always in full view of his load; and when the cargo is nearly exhausted, he can place his bucket in the most advantageous position. As the buckets are designed to hold ten tons of ore, and make more than one bite per minute, one of these machines will handle over 600 tons per hour. Four machines working together have unloaded a cargo of iron ore of 7,200 tons in four and a half hours —a record that should satisfy the most exacting shipowner. These unloaders are fitted with a separate powerful motor for each motion. That for opening and closing the bucket develops 80 horse-power; that for operating the rocker, 150 horse-power; while that for moving the whole machine—a weight of 900 tons—along the quay is 260 horse-power.

Special Boats.

We may note that in connection with these unloaders a special type of boat has been evolved. The boilers and engines are placed right at the stern of the vessel and the navigating bridge and crew space right forward, leaving the whole of the body free for ore. This space is ample to allow four unloaders to work in it simultaneously. The hatch-covers are made to slide, so that all areas of the bunker space can be uncovered in turn. Moreover, the shape of the boat is such as to enable the unloader to reach all parts of the hold. In the later boats, 96 per cent. of the cargo has been unloaded without the aid of shovellers, which is probably a record in the mechanical handling of material in bulk.

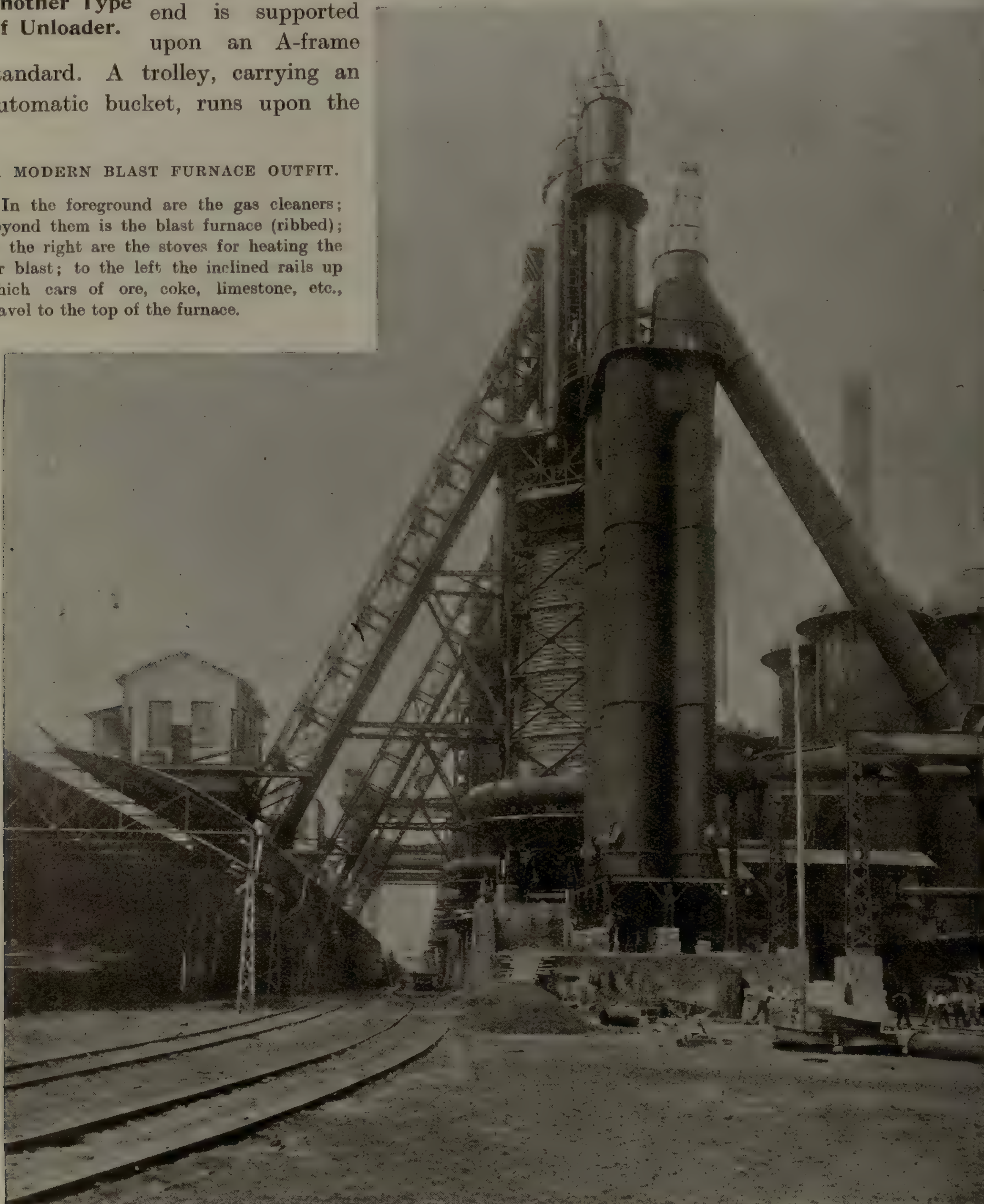
Another interesting type of machine used



A CAR DUMPER EMPTYING A RAILWAY ORE CAR (A) INTO A BOTTOM DUMPING CAR (B).
One wheel of A is seen, pointing upwards.

for unloading, and also for stocking and re-handling, consists of a large bridge having a cantilever extension at one end for reaching over two or more railway lines or out over a quay. The other end is supported upon an A-frame standard. A trolley, carrying an automatic bucket, runs upon the lower inside flanges of the bridge, and is rope operated—that is, the motions are transmitted by ropes to the trolley from hoisting and travelling mechanism contained in the front tower.

Another Type of Unloader.



A MODERN BLAST FURNACE OUTFIT.

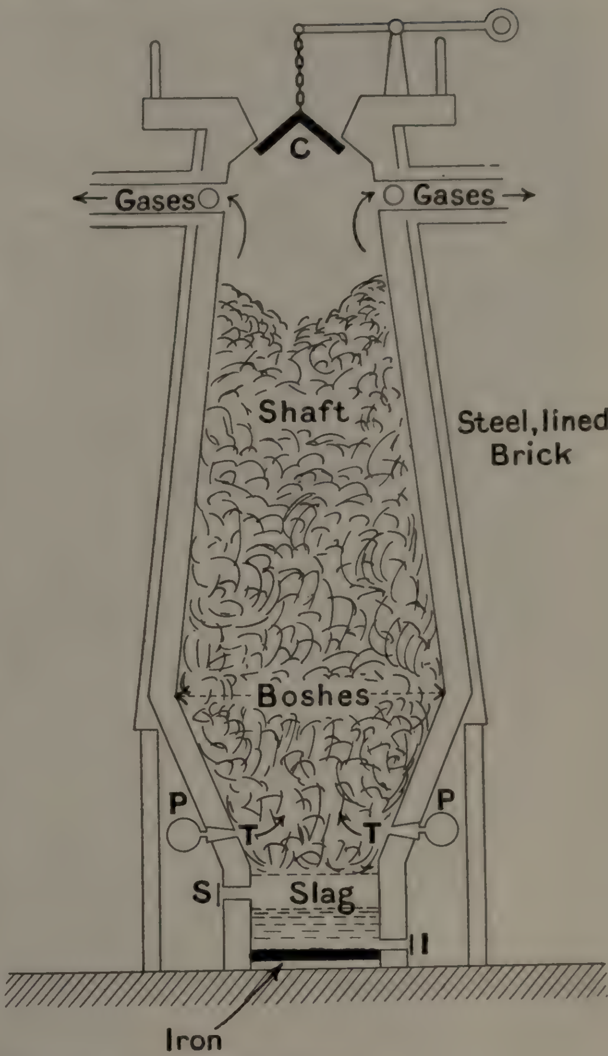
In the foreground are the gas cleaners; beyond them is the blast furnace (ribbed); to the right are the stoves for heating the air blast; to the left the inclined rails up which cars of ore, coke, limestone, etc., travel to the top of the furnace.

The operator travels with the trolley, the motions of which he governs by means of magnetic controllers, and always has a clear view of what is being done. The automatic buckets for this class of machines hold up to seven tons of ore, which can be dumped upon the top of the stock pile or into the railway trucks as required. These bridges are designed for quick operation, and are able to shift 1,500 tons each in ten hours—an achievement which necessitates the trolley travelling at a speed of 800 feet per minute along the girders. Their use is not confined to ore handling, for when fitted with lighter buckets they are employed to shift coal and limestone.

From the transportation and loading we pass to the next process in steel-making—namely, the introduction of the ore into the blast furnace which extracts from the ore the iron from which the steel is manufactured.

Blast Furnaces.

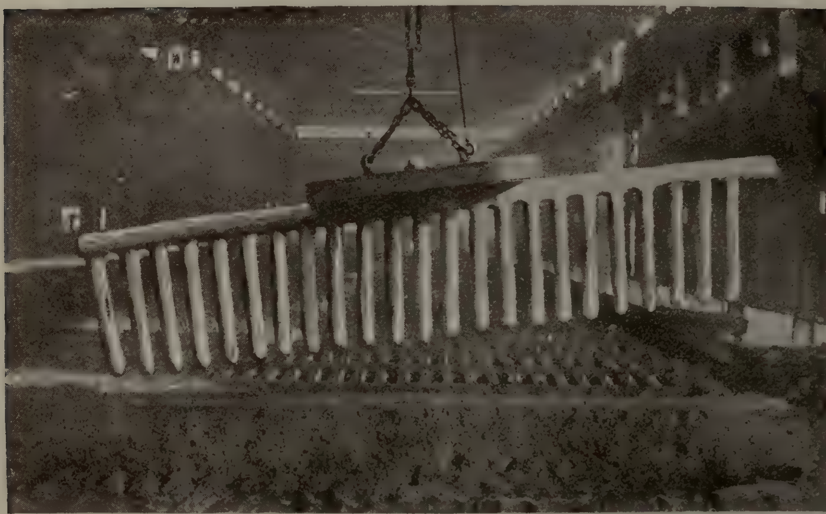
A blast furnace consists of a huge column of brickwork inside a metal casing, shaped like a chimney, from 75 to 100 feet high, and about 20 feet in diameter at the largest part. At the top it is contracted and fitted with a bell to keep the gases from escaping. From the widest part, about 18 feet from the ground, the furnace tapers downward sharply to about 8 feet in diameter at the bottom. This lower tapered part is called the bosh. At several points round the bosh the air of the blast enters through water-cooled pipes called tuyères. The contents of a blast furnace are, to put it briefly, a column of alternate layers of coke, ore, and limestone, varying in temperature from a white heat at the tuyères to a black heat at the bell. The chemical reactions that take place provide the heat necessary to separate the metal from the refuse. For the full details of the process we must refer the reader to a good book on metallurgy.* The interesting feature of a blast furnace from a mechanical point of view is the method adopted in the United States and on the Continent for charging. A blast furnace producing 400 tons of iron per day of twenty-four hours requires three times that amount of material (1,200 tons) to be poured into it during that period. The charging installation consists of an inclined lattice girder reaching from the ground-level to the top of the blast furnace. The girder is fitted with two sets of rails, parallel to one another for the whole of their length up to



SECTION OF BLAST FURNACE.

The air blast passes from the pipe **P P** into the furnace through the tuyères **T T**. Slag is drawn off at **S**, and the liquid iron at **I**. Ore, etc., is fed in past the conical trap **C**.

* A simple explanation of the mechanical and chemical processes of iron and steel manufacture is given on pp. 207–262 of *How It Is Made*.



MAGNET LIFTING A SOW AND PIGS OF IRON FROM THE MOULDS.

from the subject of this article, we will leave it out of consideration.

Lifting Magnets.

The iron when smelted is run out into open sand-moulds arranged in the form of a comb directly in front of the blast furnace. (The castings are subsequently broken up into pieces called pigs, whence the term "pig"-iron.) For lifting the unbroken combs out of the sand, electro-magnets of the ironclad type, and specially designed for this work, are now successfully employed. The whole of the electric wiring is enclosed within metal, and the shape is such that as many as possible of the magnetic lines of force are concentrated on the pig-iron. This type of magnet is also useful for lifting pieces of scrap steel which are too large to be shovelled up, and for handling plates and hot billets of steel. A literally

MAGNET LIFTING PLATE WITH THREE MEN IN THE YARD OF THE WELLMAN SEAVER MORGAN COMPANY.

the head of the furnace, on which runs a tub containing the charge of iron ore to be emptied in at the top of the blast-furnace tower.

Automatic Tips.

This tub has four wheels, two on each set of rails. At the top the lower set of rails, upon which the front wheels of the tub run, curve over the furnace. The upper set of rails, carrying the bottom wheels of the tub, continue upwards, and by upsetting the tub cause its charge of iron ore to be tipped automatically into the furnace. The tub is hauled up by a wire-rope carried over a pulley at the top, and operated by a hoisting engine or motor situated in a building at ground-level. The engine is arranged to give a "harmonic lift," and so brings the car to rest gradually as it reaches the top, and reverses the motion of the tub independently of the operator.

Other machinery used in connection with the blast furnaces would not be of interest to any but the enthusiastic engineer, and as a description would cause a serious divergence

A SKULL-CRACKER BALL SMASHING SCRAP AT THE BALDWIN LOCOMOTIVE WORKS.
(Photo, Electric Controller and Supply Company, Ohio.)

AN "IRONCLAD" MAGNET LIFTING A 6-TON SKULL-CRACKER BALL.

striking application of the magnet is seen in the lifting of the large balls, sometimes called skull-crackers, which break up large pieces of scrap for remelting. A magnet forms an ideal means of raising these balls, for in nine cases out of ten a skull-cracker fitted with a ring for ordinary hook-tackle will fall with the ring downwards, and a lot of work and time must be expended in getting at the ring to replace the hook. Also, when a magnet is used, the ball is released merely by switching off the electric current.

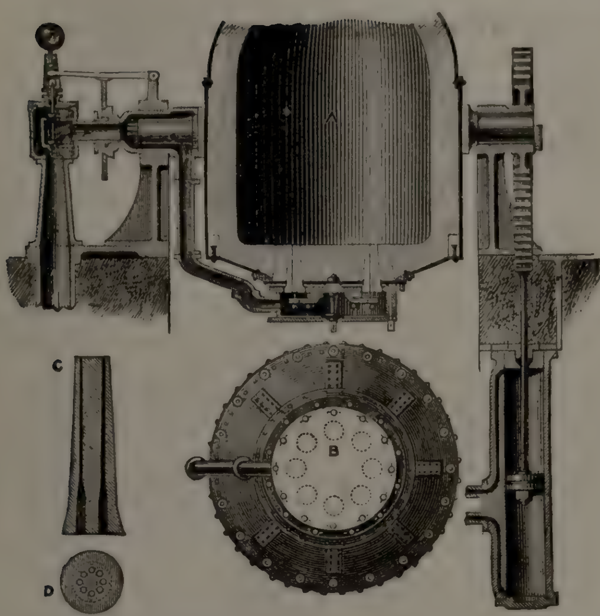
We have now outlined roughly the progress of iron from the ore to the pig stage. The next thing to consider is the transformation of pig-iron into steel. There are two principal methods of converting pig-iron into steel—the Bessemer process, and the open hearth process. The Bessemer process is the oldest, and was patented by Sir Henry Bessemer in 1855—from which year the commercial manufacture of steel dates.

The process consists in blowing air through

molten pig-iron in a suitable vessel, called a converter, and burning out the silicon, manganese, and carbon. The converter of present-day type is a large pear-shaped vessel built up of heavy steel plates riveted together and mounted upon trunnions so as to be free to rotate or tip. It is lined inside with refractory brick work, which is as much as two feet thick at the bottom, to withstand the heat. The only opening is at the top of the truncated cone-shaped spout, and the metal is teemed in and out by rotating the vessel on its trunnions. The air-blast, supplied by large blowing engines at a pressure of about 15 lbs. per square inch, enters through one of the trunnions, which is made hollow for the purpose. From this trunnion it passes down the side of the converter, and enters through openings, called tuyères, in the bottom, from which the liquid metal is excluded by the air pressure. The mouth of the converter is tipped downwards to allow the introduction of the molten iron brought from the metal-mixers. These large mixers or storage furnaces are used as reservoirs, into which the metal from the blast furnaces is teemed by means of ladles. Their use precludes the necessity for casting the iron into pigs and remelting it for the converter — which means a great economy in fuel and labour. After the metal has been poured into the converter, the blast is started and the converter brought gradually into an upright position. The condition of the charge is judged by the colour of the burning gases escaping, and great judgment is required to decide when the conversion, which lasts only about fifteen minutes, is complete. There are now several modifications of the original process, one being the Tropenas, in which the air is blown in at the surface of the metal. The capacity of converters ranges from 3 to 20 tons; from 8 to 16 tons is the most common practice. Tipping is effected and controlled by means of either hydraulic cylinders or electro-motors arranged to rotate the converter through gearing driving on to one of the trunnions.

A BESSEMER CONVERTER IN BLAST.

The Bessemer Process of Steel-making.



BESSEMER'S STEEL CONVERTER.

A, vertical section through trunnions; B, plan of bottom; C, section of tuyère; D, plan of do., showing air-holes.

The second important steel-making process is the open hearth, introduced several years after the Bessemer. Its name signifies that the steel is produced in a furnace, the metal bath of which is exposed to heated gases. To produce the high temperature—3,000° Fahrenheit—required, the furnaces are made regenerative—that is, the burnt gas is led, on its way to the chimney, through brickwork stoves which heat the fresh air and gas entering the furnace. There are two stoves—one for air, and one for gas—at each end of the furnace, and the two sets are brought into use alternately by the operation of valves. Within certain limits each reversal produces an increase in the temperature of the gases burning in the hearth. The usual temperature of the stoves at the finish is about 1,800° Fahrenheit.

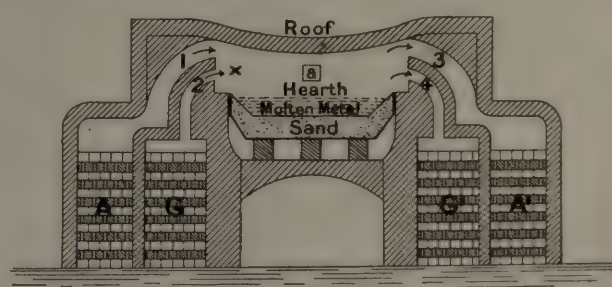
The Open Hearth Process.

The ordinary type of open hearth furnace is stationary, built up of brick, strengthened, where necessary, with metal-work. To draw off the molten metal, a hole is knocked in the bottom at one side, and the charge is run off through a spout into a large ladle. The hole is then plugged with refractory material preparatory to introducing a fresh charge. This type has little interest for the engineer.

For special purposes, however, the furnace is made to roll or tilt, so that the metal may be poured out as required. These tilting furnaces, which are constructed to hold up to 250 tons of molten steel—and, in a modified form as metal-mixers, up to 750 tons—are fine examples of the mechanical engineer's skill in overcoming difficulties caused by great weight and heat.

Tilting Furnaces.

Such a furnace consists of a large rectangular steel casing reinforced with heavy steel girders and lined with refractory brickwork. It is mounted upon rockers or rollers, whichever may be more suitable, and at each end has openings by which the gases pass in and out, and movable burners which can be drawn back to allow the furnace body to roll easily. Doors are fitted at one side for introducing metal—either molten or in the "pig" state—steel scrap, and limestone; at the other is a spout through which the finished steel can be poured, in any quantity desired, by tilting the furnace body. Tilting is usually effected by hydraulic cylinders; in some cases electrical power is used. The doors and port-



DIAGRAMMATIC SECTION OF AN OPEN HEARTH REGENERATIVE FURNACE.

A, A', stores for air; G, G', stoves for gas. Air enters by passages 1 and 3 alternately; gas through passages 2 and 4 alternately.

A ROW OF SIEMENS OPEN HEARTH FURNACES AT MESSRS. VICKERS SONS AND MAXIM'S.

A charge is about to be tapped from one of the furnaces into the suspended ladle, from which the metal will be run into an ingot mould.

ends of the largest furnaces are operated hydraulically. Coming to actual figures, we may mention that the rolling portion of a 250-ton capacity furnace weighs, with its charge, about 1,000 tons.

TAPPING AN OPEN HEARTH FURNACE.

Mechanical Furnace Chargers.

One of the greatest improvements in steel-works' practice was the introduction, by S. T. Wellman, of machinery for charging the open hearth furnace, and thereby greatly reducing the wages bill while increasing the output from the furnaces. Under the old system pigs of iron were fed in one at a time by an implement something like the "peel" with which a baker places loaves in his oven and withdraws them. A modern charging-machine will feed in four tons of iron—about 100 "pigs"—at once, at the rate of a load in forty seconds. One man suffices to work the machine, and one is needed to open and close the furnace door.

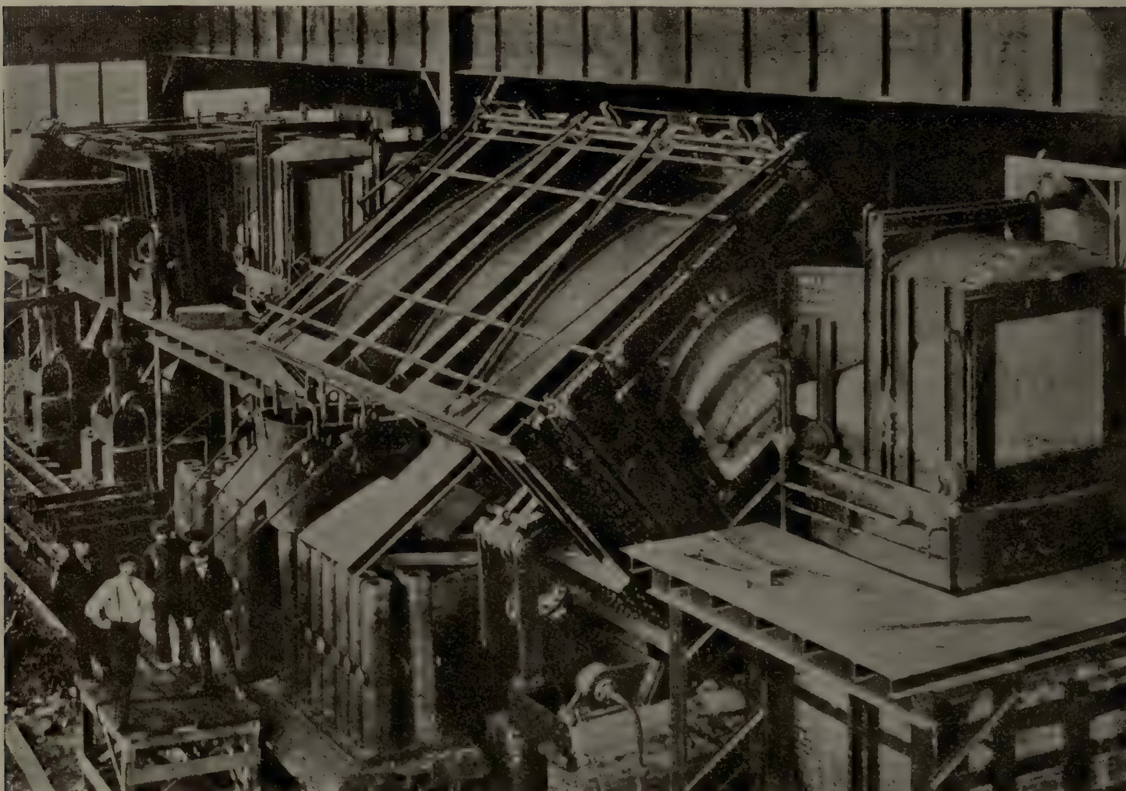
These mechanical chargers are constructed to move either upon rails on the charging platform, or upon overhead runways. We select for detailed description a machine of the second type, as being the more interesting mechanically.

At the top is a wheeled girder carriage resting on the runway. Across the carriage, towards and away from the furnaces, travels a trolley, from which depends a structure containing a vertical sliding mast. To the bottom of the mast is pivoted a charging-bar, carrying at the end either a box for pigs or a peel for large masses of iron weighing up to eight tons. The bar can be moved vertically and horizontally, and be rotated about its own axis, independently of the motions of the trolley and main carriage. The operators become so skilful as to move the bar in three senses at the same time. To charge the furnace, the box or peel on the bar is loaded; the furnace door is opened; the bar passes in and revolves, depositing its load on the hearth.

These machines are worked by very powerful electric motors and controlled by strong brakes, and so are able to start and stop very quickly.

Ladle Cranes.

The molten steel, by whatever process made, is always teemed, before being cast, into ladles which are in many cases handled by electric overhead cranes. Some cranes are able to work ladles containing 60 tons of molten metal. Their chief feature is a main trolley running on two parallel girders and provided with two sets of motor-operated lifting gear, the chains or ropes of which hang down outside the girders. The ropes or chains support a heavy cross-beam and hooks for holding a ladle. An auxiliary trolley, moving on rails between the girders, and running from end to end, is used to tip the ladle and to lift light loads. For rope suspension as many as sixteen falls of rope in four separate cables are



TWO 15-TON ROLLING OPEN HEARTH FURNACES AT HAMILTON, U.S.A.

The nearer furnace is in the tilted position which delivers the charge to the ladle seen commanding two rows of ingot moulds.

employed, so that the breaking of one rope may not mean the fall of the load and the disastrous consequences attending the fracture or sudden emptying of a ladle containing sixty tons of molten steel. All the machinery is protected from the terrific heat by baffle-plates, and the operator's cage is screened by similar plates and very thick glass.

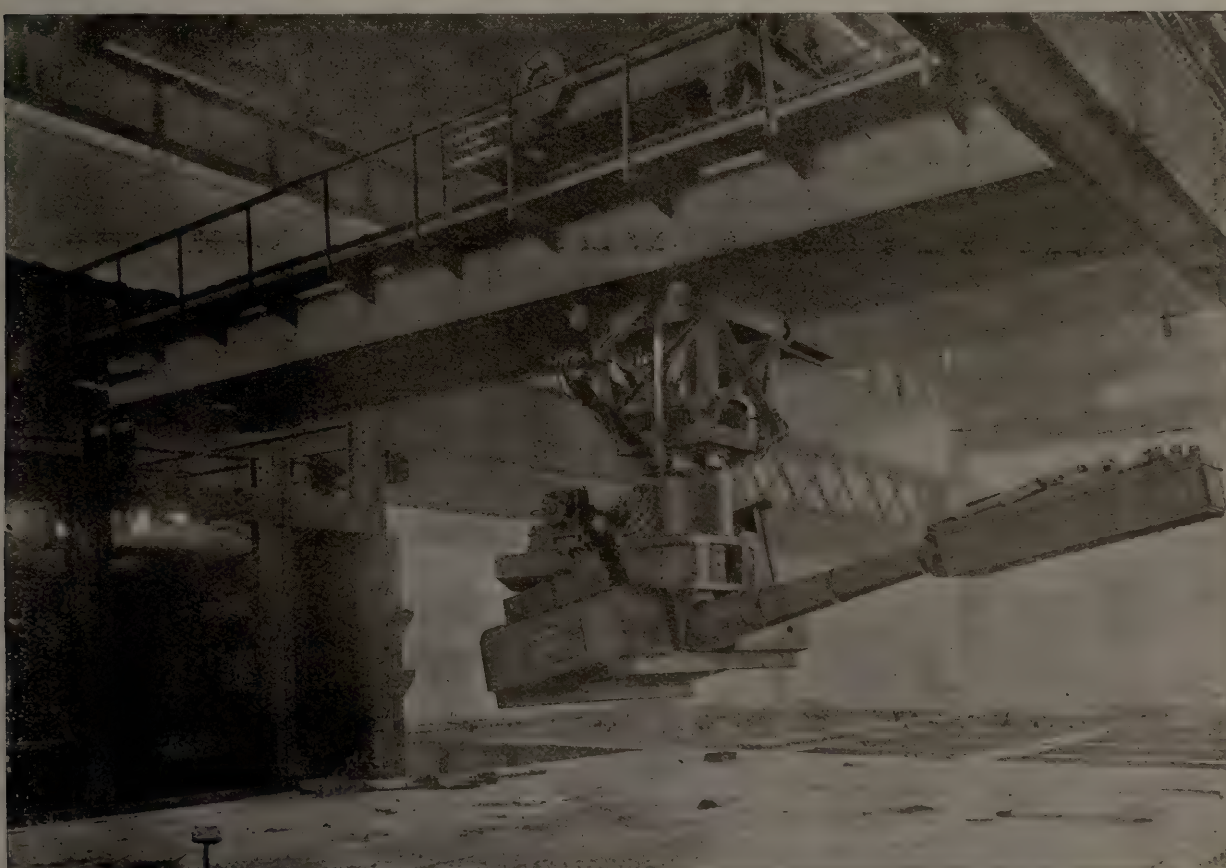
Steel intended for rolling into plates, joists, and angle bars is cast in iron moulds to form ingots. The heat so warps the moulds and roughens their interiors that the removal of an ingot becomes a task requiring the services of special hydraulic or electric machines able to exert a pressure of over 200 tons on the head of the ingot. Probably the most interesting appliance to be found in a casting-shop is a machine which removes the ingots from the moulds, and also places them in vertical soaking-pits or underground furnaces, by which they are kept red-hot until needed for the rolling-mill. These machines consist of a pair of girders mounted upon end trucks like an ordinary overhead crane. Here the similarity ends, the trolley having a braced steel guide-frame depending from it, in which slides a steel mast having at its lower extremity a pair of dogs or grippers. Five distinct motions are given to the dogs, which can handle the ingot or mould almost like a pair of hands. It is perhaps needless to add that machines of this type are operated electrically. The operator rides in a cab built out from the hanging framework, and so is able to watch his load and see right down into the soaking-pits. The travelling speed is

Ingot Extracting Machines.

often as high as 600 feet per minute, and all the other motions are correspondingly fast. Thanks to its multitudinous movements and great range of action, a single machine does the work of a great many men. One man driving the machine can, without any assistance from the ground, catch hold of the cast-iron ingot mould, push out the ingot, and set down the mould ready for the next cast. He then picks up the ingot and carries it off to the soaking-pits. The machine removes one of the lids without setting down the ingot, puts the ingot into the pit, and replaces the lid. It then returns for another ingot, and repeats the cycle of operations. When not in use for stripping and charging, the machine draws ingots from the soaking-pits and carries them to the rolls. One should remember, in order to appreciate steel-works' machinery at its full value, the high temperature of the material handled, the omnipresent dust and dirt, and the fact that the machines have to run night and day continuously for six days a week. All cleaning and adjustment must be done in the course of a few hours at the week-end.

Rolling Mills.

The conversion of an ingot into plates or sections in a rolling-mill is an interesting operation, and one that requires very substantially built machinery. For rolling rails, angles, etc., a "three-high" mill with three rolls always running in one direction is used, the sections travelling between the middle and bottom rolls in one direction, and returning between



AN ELECTRICALLY DRIVEN CHARGER FOR OPEN HEARTH FURNACES.

The charge (of pig-iron) is carried at the end of the arm, which is run into the furnace and revolved to empty the charge. By means of this machine 4 tons of pig-iron can be fed into the furnace in one operation.

the middle and top rolls. For rolling plates is employed a "two-high" reversing rolling-mill—that is, the mill has two rolls, one fixed roll at the bottom and one adjustable roll at the top, as in the ordinary domestic mangle. These reversing mills are usually steam-

the longest plates rolled by the mill. The controllers for operating the tables are placed upon an elevated platform in front of the mill, so that the operator can see all that is going on, and cause the plate to travel backwards and forwards to the rolls as required.

AN "ALLIGATOR" GRIP SLAB CHARGER INSERTING A 12-TON PLATE INTO A REHEATING FURNACE.

driven, although electric driving is now successfully employed. The rolls are made of specially hardened steel, and for a mill rolling ship or boiler plates up to 7 feet wide and 40 feet long, are about 16 inches in diameter. They are mounted in massive cast-iron guide-frames or housings with a screw-down gearing for adjusting the rollers, which in large mills is operated by electric motors. At both back and front of the mill is a table of rollers, driven generally by an electric motor, and extending over a distance sufficient to take

The rolls themselves are driven by a powerful steam-engine through a double helical spur-gear reduction, the type of gearing rendered necessary by the large power required and the heavy shocks to be borne at the commencement of each pass. Thirty to forty ingots an hour are dealt with quite easily.

For drawing the slabs out of the reheating furnace and bringing the billets or slabs to the plate-mill a machine called a slab charger is used. It consists of a pair of girders mounted on carriages running upon overhead

ways, and bearing a trolley fitted with a hanging portion built up of steel plates and angles. Within this hanging portion slides a steel framework, to the rear portion of which is attached the operator's cab, and in front is a massive cast-steel bar fitted with a suitable grip for holding the slab. The framework is raised or lowered by suitable gearing upon the trolley. It is also made to turn about a vertical axis, and travel both down and across the shop. The operator is thus enabled to pick up or set down a slab over a large range without any outside help whatever. The method of holding the slab varies with the conditions of working. Sometimes the machine is arranged to grip the ingot by the sides, and sometimes by the ends. Then there is what is termed an "alligator" grip, which seizes the slab as between the thumb and finger. A special feature about the grips is that they are so designed that the pressure required for holding is derived from the weight of the ingot itself, and any slackness through shrinkage of the ingot by cooling is automatically taken up. Machines of this type handle quite easily slabs up to twelve tons in weight.

Slab Chargers.

It now only remains to cut up the finished product into the length required, and to load it into wagons for transport. For cutting up the plates, etc., a machine called a shears is used, furnished with two blades working on the same principle as those of a pair of scissors. These machines are of enormous power, and will shear a cold plate 10 feet wide and 1½ inches thick at one stroke. They are operated by hydraulic power and fitted with steam intensifiers. Some of the large shears designed for shearing armour plates exert a pressure of 5,000 tons. In appearance they suggest a very massive hydraulic press having a fixed blade at the bottom and a moving blade attached to the hydraulic rams. The shears are, of course, fixed, and the material has to be brought to them, generally by overhead cranes.

Shears.

For stocking the material in the yards and loading it into wagons there are special cranes, either of the Goliath or gantry type, covering a range of sometimes 150 feet. They are fitted with magnets for handling the material, are electrically driven at high speeds, and effect a great economy over the old jib cranes.

The machinery described in this article does not by any means comprise the whole of that used in a steel works. In fact, not one-quarter has been mentioned—only those parts of the plant that are most interesting. If the reader wishes to go further into the subject, he should obtain permission to visit a large steel works, and see for himself to what a pitch of perfection the rapid handling of hot and heavy material has been brought.

[NOTE.—*Thanks are due to Messrs. Wellman, Seaver, and Head, Ltd., for supplying many of the photographs illustrating this article.*]

THE JETTY AT THE HEAD OF LOCH LEVEN, AND ELECTRIC RAILWAY TO THE ALUMINIUM WORKS.

THE KINLOCHLEVEN WORKS OF THE BRITISH ALUMINIUM COMPANY.

An account of the greatest Water-Power Installation in the United Kingdom.

Aluminium.

THOUGH aluminium is the most widely distributed of metals, being a constituent of all clays, it was, until about twenty years ago, very expensive, owing to the great difficulty experienced in separating it from the other substances with which it is combined. Wöhler first isolated it in 1827 by a chemical method, which was gradually improved upon during the following sixty years. In 1885 electrical processes of separation were first tried, and shortly afterwards the production of the metal on a large scale, causing a drop in the price from about 20s. to 5s. a pound, commenced. At the present time aluminium may be bought at prices ranging from sevenpence to a shilling per pound, according to the state of the metal market and the form in which it is required.

Its uses.

The most noticeable property of aluminium, its low specific gravity—only 2·65 times that of water—makes it very valuable for many purposes where the saving of weight is important; for instance, in the crank-cases of motor-car engines. The same quality, combined with the ease with which the surface may be kept clean, makes the metal very suitable for cooking utensils. Another point in its favour is its softness, which renders it easily worked on the lathe, rolled, and drawn. In combination with certain other elements it forms alloys which are very tough as well as light, and will find an extended sphere of usefulness as their advantages are more fully recognized.

For electrical purposes aluminium is becoming a formidable rival to copper. Its smaller conductivity and tensile strength are more than offset by its much smaller weight, so that aluminium is now employed exten-

sively for the transmission of high-tension current, especially in America. To take a couple of instances: aluminium conductors deliver current from the generating station at Snoqualmie Falls to Tacoma, 44 miles away; and from Electra to San Francisco, 154 miles. Spans are made longer with aluminium than

Aluminium Conductors.

alumina is introduced. The current passes from one pole to the other through the cryolite and alumina, encountering a resistance which develops an exceedingly high temperature, and by electrolytic action causes the aluminium to separate and sink through the liquid cryolite to the bottom of the furnace, whence it is drawn off.

SKETCH MAP SHOWING THE BLACKWATER DAM, THE CONDUIT, THE PIPE TRACK, AND THE FACTORIES.
The broken line shows the route of the cableway used for transporting material from the loch to the Dam site.

with copper conductors — one across the Niagara River is of 2,192 feet—and this effects a considerable economy in poles and standards.

For underground insulated cables a well as fo overhead conductors aluminium has a future before it. When one considers the enormous development of electrical power schemes, and the fact that the cheapening of conductors will hasten that development, the importance of aluminium among metals is sufficiently established on this head alone.

The electrical method of reduction consists, to describe it briefly, of subjecting pure oxide of aluminium—alumina—to the intense heat of an electric furnace. The furnace is an iron box lined with carbon. To an iron plate at the bottom is attached the cathode, or negative pole, of the dynamo. The positive pole is a bundle of carbon rods so arranged that they can be moved vertically. Cryolite is fed into the cell and melted, and then the

The Electric Furnace.

The alumina used is prepared by drenching a substance called bauxite with a solution of caustic soda. This chemical combines with the alumina to form sodium aluminate, which is subsequently treated with hydrated alumina. The hydroxide, when dried, is ready for the furnace.

As the electric furnace requires a large volume of current, the latter must be obtainable at a low cost to render the manufacture of the metal profitable. The huge power-stations at Niagara Falls, where electrical energy is generated on so large a scale that current is remarkably cheap, have led to the concentration round the Falls of great aluminium factories, and have made the district the chief world-centre of the aluminium industry. In the British Isles manufacturers have been handicapped by lack of natural water-power. We have no waterfalls over which a sufficient volume of water passes at all times of the year to work power plants

Need for Cheap Current.

THE UPSTREAM SIDE OF THE BLACKWATER DAM, WHICH HOLDS UP A LAKE OF 3,300,000,000 CUBIC FEET CAPACITY AND OVER SEVEN MILES LONG.

comparing in size with those of America, Scandinavia, Switzerland, and Italy.

The enterprise which forms the main subject of this article has overcome the difficulty by impounding at a high level the water of a mountain watershed, and so ensuring an abundant supply for power requirements from year's end to year's end.

Kinlochleven.

On the west coast of Scotland is a broad sea opening named Loch Linnhe, sheltered from the open Atlantic by the Island of Mull. Opposite Ballachulish the loch bifurcates. One arm, Loch Eil, runs ten miles or so in a north-easterly direction, and then turns abruptly westwards for another ten miles. The other arm, Loch Leven — which must be distinguished from the more famous loch of the same name in Kinross—runs due west. A mile inland from its head, on the river Leven, is Kinlochleven, situated amid the wildest of scenery, and yet the site of a great industry, for here are established the new works of the British Aluminium Company, opened early in 1909. No chimneys belch volumes of disfiguring smoke, the usual accompaniment of manufactures—the air is as pure as ever it was, for King Coal does not rule in this industrial village.

The Dam.

Following the Leven River $5\frac{1}{2}$ miles from the head of the loch, we reach, at an elevation of about 1,000 feet above sea-level, a huge dam of concrete, nearly three-quarters of a mile long, stretching from side to side of the valley. It is 80 feet high, and in width tapers from 62 feet at the foundations—sunk into the solid rock—to 10 feet at the top.

A BRIDGE SECTION OF THE REINFORCED CONCRETE CONDUIT FOR LEADING THE WATER FROM THE DAM TO THE HEAD OF THE PIPE LINES.

The dam has formed a lake over seven miles long, and having at high-water level a capacity of 3,300,000,000 cubic feet.

The Reservoir.

Three small lochs at slightly different elevations have been swallowed up by this great sheet of water. The reservoir is fed by the annual rainfall of about 100 inches on a catchment area of between 55 and 60 square miles, so that there is little risk of the water ever running short, even if the factory is kept at full pressure.

At the dam commences a conduit of reinforced concrete, 8 feet square in cross-section. This leads the water 3¾ miles along the side of the valley, on a gradient of 1 in 1,000, to a penstock chamber situated 965 feet above sea-level. From the penstock chamber the water passes

The Aqueduct.

through six — there will be eight eventually—parallel lines of 39-inch pipes to the generating station, 1¼ miles from and 922 feet lower vertically than the end of the conduit.

The pipes, made of solid welded steel, are 20 feet long each. They rest on concrete pedestals, and at every bend, whether in the vertical or the horizontal plane, are attached to massive concrete anchorages. The total weight of the metal in the six lines exceeds 6,000 tons.

PIPE TRACK AS SEEN FROM NEAR THE BOTTOM END.
Observe the massive anchorages at the angles.

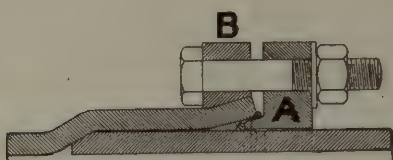
At the station end each pipe line communicates with two "bus" pipes, both of which are connected to all the water turbines. This arrangement permits the inspection and repair of either bus pipe and any one of the pipe lines.

The form of joint used is illustrated by the accompanying diagram. Lead caulking of the ordinary type would not be suitable for pipes subjected to such high pressures as these have to bear—over 400 lbs. to the square inch at the station end—and exposed to the open air.

Pipe Joints.

The "muff" joint employed is made water-tight with a packing of rope forced into the space between the spigot of the splayed end of the socket by the projecting lip of a collar (A), which

is drawn towards the socket by screw bolts passing through it and a second collar (B), embracing the splayed portion of the socket. This collar is tapered on the inside to the same angle as the socket. The tightening up of the bolts forces the packing into place, and also presses down the socket on



SECTION THROUGH A "MUFF" JOINT IN USE ON THE PIPE LINE.

to the packing by virtue of the wedging action of B.

This type of joint permits every pipe to expand and contract longitudinally without causing leakage, and renders it possible to insert a new packing while a pipe is under full working pressure.

The water turbines in the power-house were made by Escher, Wyss, and Co. of Zurich, and

Pelton Wheels.

are of the well-known high-pressure Pelton wheel type, with spoon-shaped buckets set in pairs round the circumference of the wheels. A good idea of the rotating part of a turbine, with buckets shaped somewhat differently, is afforded by the photograph which is reproduced by permission of the Pelton Wheel Company of San Francisco.

Nine of the wheels have an over-all diameter of 8 feet, and an output of 3,200 horse-power each; two are 6 feet in diameter, and develop 930 horse-power each. The water strikes the very sharp edge of the wall between a pair of buckets, and is deflected right and left round the inside of the buckets, losing practically all its velocity. The inner surface of the buckets is polished so highly that 98 per

A PELTON WHEEL. *(Photo, The Pelton Wheel Company.)*

cent. of the water's energy is transmitted to the buckets.

INSTANTANEOUS PHOTOGRAPH OF WATER ISSUING FROM A NOZZLE AGAINST A PELTON WHEEL.
(Photo, The Pelton Wheel Company)

The water is projected as a solid bar from a specially shaped nozzle of very hard steel carefully polished inside. The supply of water is regulated by means of a concentric tapered needle, the movements of which, effected by

hand or by an automatic governor, produce a corresponding change of the discharge area of the nozzle, and so vary the size of the jet and the power of the wheel. The pressure of the water is so great that the needle cannot be worked direct from the governor, but requires the interposition of a servo-motor to do the hard work. The governor itself is of the familiar centrifugal weight type. An increase of speed causes two weights, suspended by links from the top of a revolving vertical shaft, to fly outwards and, through two other links, to move upwards a grooved collar sliding on the shaft. A decrease in speed moves the collar downwards.

Governing the Water.

This collar operates a small valve, which in turn controls another valve admitting oil or water under high pressure to either side of the piston of a servo-motor. This piston is coupled direct to one end of a lever, which is the first of a series operating the nozzle needle valve.

INTERIOR VIEW OF THE KINLOCHLEVEN POWER-STATION, SHOWING THE EIGHT 3,200 HORSE-POWER TURBINES, AND THE EIGHT PAIRS OF GENERATORS DRIVEN BY THEM.

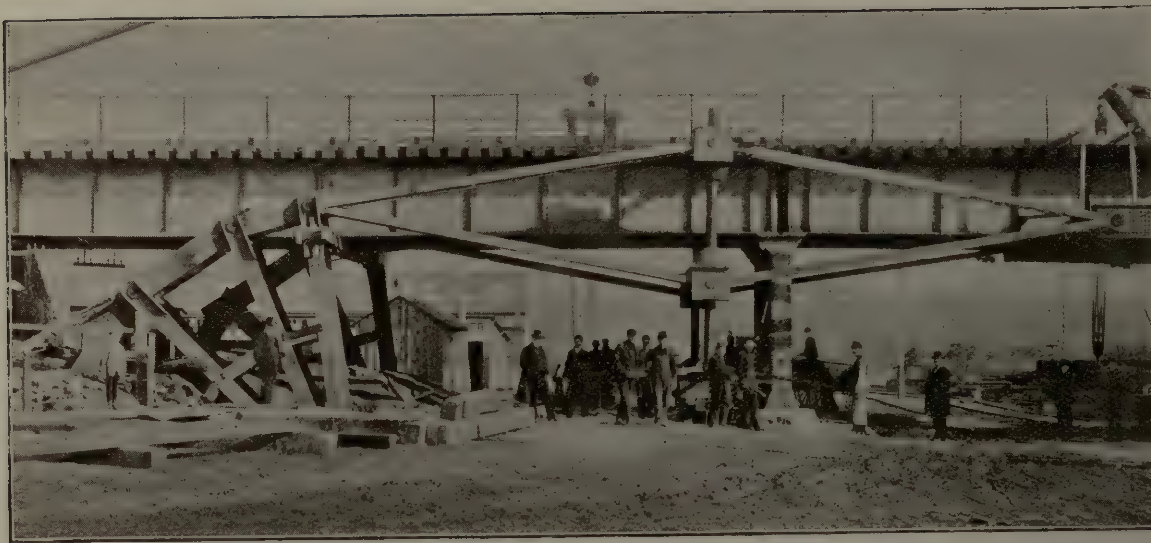
As a sudden diminution in the discharge would naturally cause a great temporary increase in the pressure of the pipes, the speed governor is arranged to perform a second duty—that of opening an escape valve when the needle valve is closed, and closing it when the needle valve is opened. The two valves are so adjusted that under all conditions the total amount of water passing through them remains unaltered. If a stoppage of the turbine becomes necessary, its sluice valve is shut gradually by hand.

Each turbine is connected direct to a pair of generators mounted on a single shaft of mild steel. Each of the main generators has a normal full load output of 1,000 kilowatts, when rotating at its normal speed of 300 revolutions per minute. As these generators have to run at full pressure continuously for months at a time, provision is made for effecting all necessary adjustments, renewal of brushes, lubrication, and cleaning while they are in motion.

The Generators.

Sets of smaller dynamos are used for lighting the factory and village and generating current for the double-track electric railway which connects the factory with a quay at the head of Loch Leven.

[NOTE.—*Thanks are due to the British Aluminium Company Ltd. for supplying much of the information in this article and several of the illustrations.*]



THE ADJUSTING TOGGLE USED FOR LOWERING THE CANTILEVERS OF THE RAILWAY ARCH BRIDGE, NIAGARA FALLS.

(Photo, Pennsylvania Steel Company.)

THE ARCH BRIDGES OF NIAGARA FALLS.

This article describes two notable feats of Bridge Building, in which old Bridges have been replaced by new without disorganizing traffic.

THE deep gorge below the Niagara Falls has afforded plentiful opportunity for the exercise of the bridge-builder's art. Above the Falls the construction of a bridge is rendered impracticable by the width of the river and the strength of the current; and as communication between the two banks was, and is, a matter of the utmost importance, advantage has been taken from time to time of the comparative narrowness of the chasm through which the Niagara River flows after its great leap.

In 1848 Mr. Charles Ellet erected the first of the many bridges, one of the suspension type, designed for light traffic only. Two years later a suspension bridge of 1,040 feet span—the longest of its time—was added between Queenston and Lewiston. (This was replaced in 1898 by another suspension bridge of modern design.) The third of the series was the suspension bridge built in the years 1853–55 by Mr. J. A. Roebling to carry the trains of the Grand Trunk Railway. In its original form it had a wooden stiffening truss and masonry towers. The truss was replaced by one of steel in 1880, and the masonry towers by steel towers in 1886, both operations being effected without disturbing the traffic. The fourth on the list is the suspension bridge of 1,268 feet span erected by Mr. Samuel Keefer in 1868, between Niagara Falls and Clifton. It was too narrow to serve the purpose for which it was intended, and was widened in 1886; but three years later succumbed to the

Successive Bridges across the Niagara Gorge.

buffeting of a gale which snapped the storm-guys, broke the ropes suspending the stiffening truss, and caused the latter to fall into the river. Shortly after this disaster the bridge was in use again, with a new girder attached to the cables, which fortunately had not been damaged by the accident.

The most recent of the original bridges is the cantilever structure built across the gorge in 1883 for the Michigan Central Railroad. This bridge has a central span of 495 feet.

Need for Replacing the Grand Trunk Railway Bridge.

Early in the 'nineties it became evident that the Grand Trunk Railway Bridge, with its single track of rails, was inadequate for handling the traffic, and the task of making the necessary alterations had to be faced. It was decided to replace the suspension with an arch bridge resting on four points of supports half way between water level and the crests of the cliffs on either side of the gorge.

CONSTRUCTING THE CANADIAN SIDE ABUTMENTS FOR THE RAILWAY ARCH BRIDGE.

The arch, designed by and erected under the supervision of Mr. L. L. Buck, M.Am.Soc.C.E., has an arch span of 550 feet, connected at each end with the bluff by a girder span of 115 feet. The platform truss has two decks —an upper one for a double railway track, a lower one for a carriage way and foot-passenger paths.

The Arch.

The arch was designed to carry a load of 5,500 lbs. per foot run on the upper, and 3,000 lbs. per foot run on the lower deck. One important condition of the contract was that erecting operations should not interfere in any way with the running of trains on the old structure until the time should come for transferring the traffic to the new. It should be pointed out here that the axes of the old and new bridges coincided.

Abutments and Skewbacks.

Operations commenced with the erection of timber falseworks to support the shore spans during erection, and afford a path over which material for the main arch should be moved. These structures, which had a maximum height of more than 100 feet, consumed a very large quantity of timber. The next thing to be done was to

SETTING THE SKEWBACK CASTINGS FOR ARCH HINGES.

RAILWAY ARCH BRIDGE, SHOWING CONSTRUCTION AS ON MARCH 16, 1897.

In the background is the cantilever bridge of the Michigan Central Railroad.

place the pedestals of the skewbacks at the points of support of the arch. Each pedestal was a casting weighing 23 tons, so that the task of getting it on to its masonry foundations and aligning it with the exactitude necessary to ensure the accuracy of the closing of the arch was not an easy one. The impossibility of erecting any support in mid-stream made it necessary to build out the arch as two cantilevers from each bank to a point of meeting. To give proper support for the cantilevers, four holes were excavated in the solid rock to receive large steel grillages filled in with concrete. These grillages took the strain of four sets of anchor chains running to the tops of the first bents or uprights of the cantilever. Each chain was composed of such of the eye bars and top chord sections of the 115-foot spans as could safely be used for the purpose, and of odd members of suitable shape and strength.

Anchorages.

The designer included in each chain a toggle, or diamond-shaped frame, hinged at each corner, with its longer diameter lying in the direction of the chain. The outer end was attached to the chain, the inner to the anchorage. Through the top and bottom hinges passed a right- and left-handed screw, 17 feet long and 9½ inches in diameter, furnished with a capstan, the turning of which would alter the shape, and consequently the length, of the toggle, and move any weight supported by the chain. (See diagram on page 285.) This device made it an easy matter to adjust the positions of the cantilevers exactly when the time came to join up the arch. Twelve men at each of the two capstans sufficed to lower a cantilever, and double that number was required to raise it, the complete cantilever weighing about 500 tons. The toggles proved an entire success. Thanks to the care with which the

Adjustment Toggles.

ARCH CONNECTED, MARCH 28, 1897.

pedestals had been placed and the arms built out, the rivet holes at the ends of the arms overlapped within a small fraction of an inch, when the toggles were slacked away, to the extent calculated beforehand.

Travellers.

Two "travellers," running on the top chord of the new structure, were used to build out the cantilevers. After the arch had been closed, the lower floor, carrying the tracks for trolley cars and road traffic, was built up, and employed to bear the weight of the old suspension truss, which could then be removed piece by piece to make room for the upper deck. As soon as this part of the work was completed, it only remained to cut and remove the cables and to demolish the towers.

Bridge Test.

For the official tests the bridge was loaded with trains made up of several ten-wheeled "consolidation" locomotives, and of coal cars burdened with rails, to bring up the total weight to 7,000 lbs. per foot run. The deflection at the centre of the arch proved to be slightly less than one inch, a result which was considered to be highly satisfactory.

The Niagara Falls and Clifton Bridge.

The replacement of the Niagara Falls and Clifton road traffic suspension bridge by a steel arch bridge comprised operations very similar to those required for the construction of the railway arch bridge described above. The same system of toggle adjustment in the anchor links was used, and the two halves of the arch were built out as independent cantilevers to the point of closure.

Its Huge Arch Span.

If for no other reason, this bridge would be remarkable on account of its great span, which gives it at present the first place among the single-arch bridges of the world. Its main span of 840 feet has as yet not been approached within a couple of hundred feet by that of any other similar structure. The central span is connected with the top of the bluff of the gorge by inverted bowstring

girders, 190 and 210 feet long, on the New York and Canadian sides respectively. The arch has two parabolic braced ribs, about 26 feet deep, divided into twenty main panels 42 feet long. From the top of each of the main panel points vertical latticed posts extend to the floor of the bridge, which they support. At the skewbacks the ribs are 68½ feet apart, centre to centre; at the middle of the arch, 30 feet apart. The hinges at the skewbacks, which take the entire weight of the arch, are pins 5 feet long and 12 inches in diameter. The floor of the bridge is 46 feet 3 inches wide, divided longitudinally into two outer side-walks, 3 feet 9 inches wide each, a central double trolley car track, 22 feet 9 inches wide; and two 8-foot carriage ways between car tracks and side-walks. Mr. L. L. Buck was engineer in charge of the construction of this bridge also.

Details of Bridge.

Some of the clauses in the specification furnished to the contractors, the Pencoyd Iron Works, may be of interest to the layman, as showing what conditions are exacted in work of this kind:—

Clauses in Contract Specification.

"Rivets must completely fill their holes.

"No rivet driven either by hand or machine may be caulked or recupped.

"Before final assembling for riveting, all surfaces which will be inaccessible afterwards must receive a thorough coat of red-lead paint.

"All sheared edges must have a ¼-inch of material removed by planer afterwards.

"Pin holes must be bored accurately to a diameter of $\frac{1}{50}$-inch larger than the pins they are to receive.

"All pin holes must be smooth and accurately bored.

"Loops in iron rods must be so welded that the weld shall be strong enough to break the body of the rod."

A difficulty that the engineers had to face was that the centre line of the new bridge did not coincide with, or run parallel to, that of the old bridge. At the Canadian end they met; at the other they were nearly 17 feet apart, the new bridge being south of the old. This was due to the Cataract Construction Company's discharge tunnel having its outlet at the point where otherwise the New York skewbacks would have been placed. Another difficulty lay in the fact that the north rib of the arch would strike the bottom chord of the north stiffening truss of the suspension bridge about 100 feet from the centre. This necessitated the reinforcing of the top half of the trusses, so that, when the time should arrive, the bottom half might be cut away without rendering the trusses useless.

Difficulties to be overcome.

The plan adopted for the construction of the arch was as follows: To start the arch in such a manner that at a temperature of 60° Fahrenheit the bottom chords of the arch should meet exactly, and be pinned temporarily, to form a three-hinged arch. (The other two hinges would, of course, be at the skewbacks.) The top chords of the two panels nearest the centre, hitherto omitted, would then be finished, and subjected to pressure to impart the due amount of stress while they were joined up, so converting the structure into a two-hinged arch.

Plan for Erecting the Arch.

The anchorages for the bars which would take the weight of the cantilevers during erection were sunk in pits of such depth that the weight of rock above would of itself suffice to counteract the pull of the completed cantilevers. Next to an anchorage came a toggle joint, to the outer end of which was attached the first of the anchor links running to the top of the first post. To support a cantilever and distribute the strains properly, secondary anchorage bars ran from the top of the first post to panel points 2, 4, 6,

Anchorages and Anchorage Bars.

8, 10, 12, and a main line of bars to panel point 14. With the exception of the last, these bars had a screw adjustment at their lower ends. That running to panel point 14 was of exactly the length calculated to be sufficient. After the closing of the arch all these bars were, of course, removed.

Work on the foundations began on Sep-

anchor bars. Then the toggle joints were opened to pull the first bent back slightly, and give the cantilever such an upward inclination that the sagging caused by the gradual addition of weight should bring the extremity of the cantilever into the exact vertical position for closure with the end of the other cantilever.

ALL STEELWORK ERECTED, JULY 31, 1897.

tember 9, 1895, and was completed on the first day of the following June. The heaviest items to be handled were the pedestals of the arch, weighing 16 tons each, which had to be brought to the edge of the gorge on both sides of the river and lowered into place by means of tackle attached to the cables of the suspension bridge. When the hinges were in place, the arch was built out to panel point 2 on timber falsework, and attached at that point to the first of the secondary

Foundations built.

Cantilevers commenced.

Owing to the non-coincidence of the centre lines of the old and new bridges, the handling of material could not be effected as conveniently as in the case of the railway arch, and the stiffening trusses of the suspension bridge had to be employed to support for cranes with jibs swinging out laterally. To avoid undue twisting and straining of the trusses, loads had to be lowered from both sides of the cranes simultaneously, and the weight of a single load had to be restricted to 6 tons. Interference of the truss suspenders

Handling Material.

with the jibs was provided for by shifting the jibs vertically.

When construction had reached panel point 15 on the Canadian side, and point 17 on the New York side, it became necessary to remove the entire floor system of the suspension bridge to give room for closing the arch. The old bridge trusses were therefore removed entirely, except the top chords, between the points mentioned, completed, a timber floor, supported by the suspension cables, was built across the gap, and road traffic was resumed after an interruption of but four days.

Interference with Old Bridge.

Construction was greatly hampered at this period by rain and by very high winds, which deposited the icy mist from the Falls on the steel work and ropes, making work very dangerous for the men. No accident of any kind occurred, however, and in due course the clo-

Climatic Obstacles.

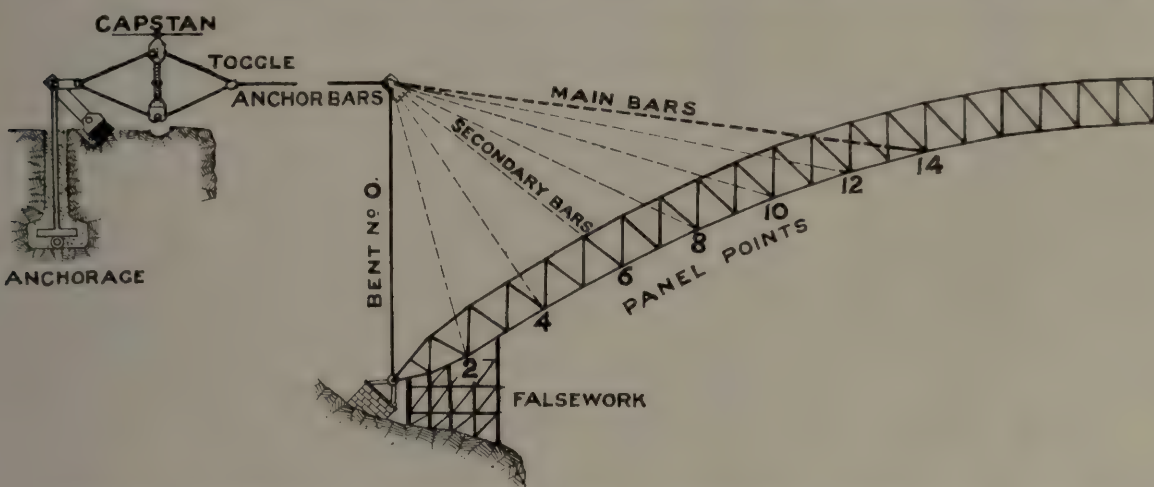


DIAGRAM TO SHOW METHOD OF ANCHORING THE CANTILEVERS OF THE NIAGARA FALLS AND CLIFTON ARCH DURING CONSTRUCTION.

The dotted lines indicate the anchorage bars carried from the top of Bent No. 0 to Panel points 2, 4, 6, 8, 10, 12, 14, to support the cantilever until closure with its fellow. The adjustable toggle and anchorage are represented on a greatly exaggerated scale.

and erection proceeded as usual. The north rib of the arch rose between the two cables of the old bridge, and the south rib some distance outside. As the south cable was in line with the two top chords of the arch, the horizontal cross bracing between the top chords could not be added at once, and its place was taken by temporary timber struts resting against the lower chords. On April 17, 1897, the lower chords of the two cantilevers met, and with such precision that the pull exerted by an ordinary hand winch sufficed to draw the eyes into the exact position which allowed the driving of the great centre pins. The closure of the bottom chords sure of the top chords was effected with the aid of hydraulic rams. After the adjustment of the arch had been completed, the joints of the chords were all examined, and found to be absolutely perfect, no packing between bearing surfaces or reaming of rivet holes being required. The results attained indicated an exactness of calculation, field measurements, and shop work rarely if ever equalled.*

Exactitude in Calculation.

After the final closure the anchorage bars were removed, and the vertical bents to support the roadway erected wherever the trusses of the old bridge permitted. Then com-

* *Engineering.*

VIEW OF COMPLETED RAILWAY ARCH BRIDGE.

Cantilever bridge in the foreground.

menced the laying of the steel floor system, this part of the work being conducted from the centre outwards. Openings were left in the floor for the south suspension cables, which were not removed until the bridge had been completed except for the filling-in of these openings. In short, the floor system was built round the cables.

While the floor was laid between panel points 18 on each side of the centre, the bridge had to be closed to traffic for one day. During the rest of this part of the construction two movable bridges were used, and shifted along to span the gaps between the completed arch flooring and that of the suspension bridge, as lengths of the latter were demolished to make room for the steelwork.

The building of the arch itself occupied but thirty-two working days, and the erection of the 2,200 tons of steelwork was completed in less than six months—a remarkable achievement, considering the difficulties to be overcome.

An Ice Jam and its Results.

During January of 1899 ice came from the Falls in great quantities, and piled up in the gorge to a height of 25 feet above water. The ice-field, firmly anchored to both shores, gradually thickened downwards, and choked the waterway, so causing the water to rise until it flowed over the ice. The increased hydrostatic pressure broke the jam. The ice swept down the gorge to the masonry abutments of the new bridge, rose above them, and struck the steelwork of the ribs, by which it was shaved away quite cleanly. The bridge quivered from end to end, but did not sway. After the ice had passed, and an examination of the bridge was possible, the damage was found to be confined to the bending of four members, which were straightened immediately. During the next summer, as a precaution against future troubles of the same kind, heavy concrete walls were built round the abutments.

[NOTE.—*For the photographic illustrations of the Grand Trunk Railway Bridge which accompany this article, we are indebted to the Pennsylvania Steel Company.*]

OLD-FASHIONED THRESHING OUTFIT USED NEAR CALGARY, ALBERTA.

(Photo, by courtesy of the Canadian Government.)

AGRICULTURAL ENGINEERING.

AGRICULTURE is the greatest of all industries, as regards the number of people who busy themselves in it, and is also the most important, since on it ultimately we depend for our very existence. A single general failure of the world's harvests would depopulate the globe, so small are our reserves of provisions. In former times, when means of distribution were undeveloped, large districts — even whole countries — suffered famine inevitably as the result of crops being ruined by unseasonable weather. Even to-day —witness parts of Russia, India, and China —the same evil recurs with distressing frequency.

The Value of Machinery.

To make easy the distribution of food-stuffs we have built thousands of miles of railway, and constructed fleets of ships specially adapted for conveying grain and other food-stuffs in bulk. Our engineers have carried out —as noticed on previous pages—many great works for rendering cultivable large tracts which are naturally unproductive owing to the absence of a sufficient and well-distributed rainfall. But all these achievements would be deprived of half their value had not the actual tillage of the ground and the sowing and gathering of the crops, and the preparation of the same for market, received a proportionate share of the attention of the engineer. It is true that agriculture can be, and has been for many thousands of years, conducted with the simplest of tools. But the simpler the tools the greater must be the number of persons required to use them to effect a given quantity of work; and had we persisted in the agricultural methods of even a century ago, the proportion of persons employed on the land would be necessarily so many times greater than it is, that other industries upon which we depend for our comfort could not have reached their present stage of development.

The introduction of highly efficient agricultural machinery has not only relieved the labour market and cheapened the price of food-stuffs; it has also enabled the farmer to make fuller use of weather suitable for the preparation of the land and the ingathering

of his crops with the labour which he can command at short notice—a fact whereof the importance can hardly be over-estimated. As much work is now done by one man and a machine as formerly by twenty men without machines. In some of the latest types of implements it may be said that they are well-nigh independent of human control, doing their work almost as automatically as the most wonderful of the mechanisms to be found in our factories. Their variety is so great that in the following pages we must restrict ourselves to noticing those which are of greatest general interest.

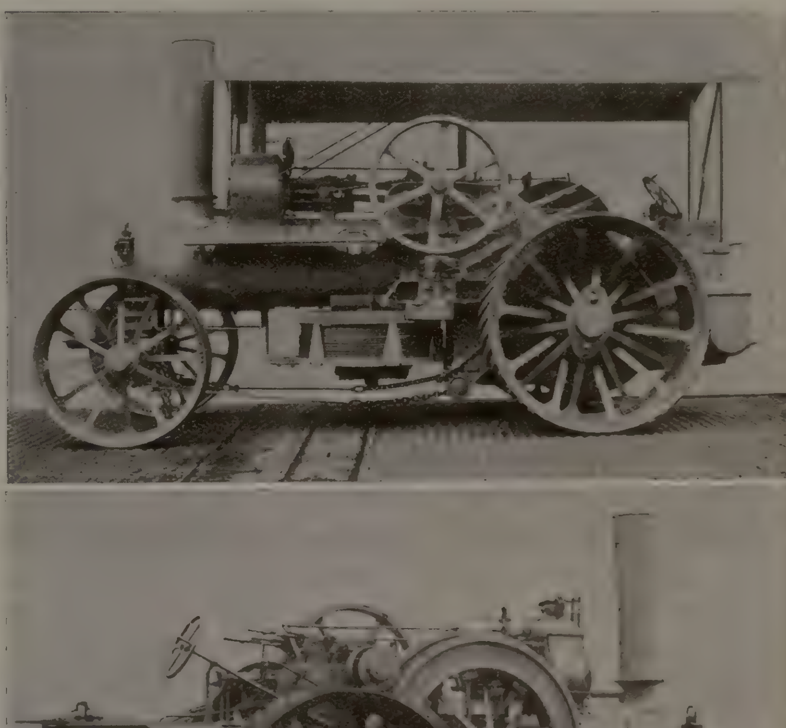
To begin at the logical point—namely, the breaking-up of the land in readiness for the sowing—we may consider, first of all, the ploughs, cultivators, harrows, and other earth-shifting devices moved by the agency of steam.

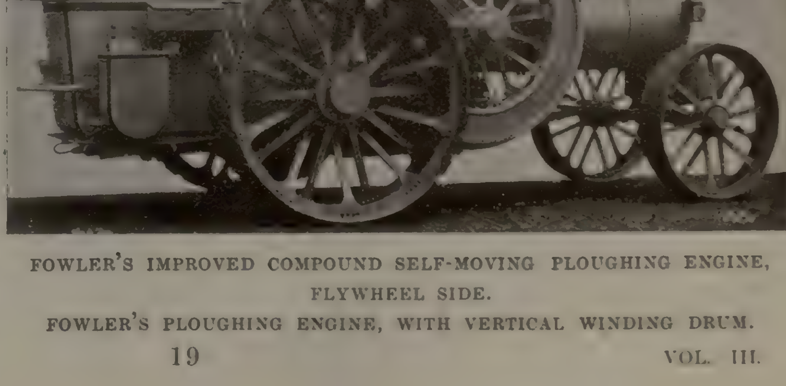
Steam Tillage.

The system of steam tillage originated about half a century ago, when an English engineer, John Fowler, introduced a steam tackle for operating a plough with three or more shares. The apparatus included, besides a steam-engine and the plough, a self-acting wheeled anchor placed on the farther side of the field opposite to the engine. The wire cable used to draw the plough passed round a drum on the engine, thence across the field to the anchor, and round a sheave on the last back of the plough. The anchor sheave could be thrown into gear with a drum, which wound in a rope passed round a pulley fixed at a point on the headland, and shifted from time to time as the work progressed. By means of this secondary tackle the anchor was advanced as required to keep abreast of the engine.

The single-engine system is still used, with the improvements evolved by experience, but only to a very small extent as compared with the double-engine system introduced in 1865, whereby the plough or other implement is drawn backwards and forwards by two engines working alternately, the "idle" one paying out cable while the other winds it in.

The advantages of power over animal cultivation are not confined to greater speed of work. Cable-drawn implements are able to





FOWLER'S IMPROVED COMPOUND SELF-MOVING PLOUGHING ENGINE, FLYWHEEL SIDE.

FOWLER'S PLOUGHING ENGINE, WITH VERTICAL WINDING DRUM.

move the ground to much greater depths—a yard or more if required—than is possible where animal draught only is employed. Land which has been cultivated for several years by animal power develops, in many cases, a hard stratum a few inches below the surface as the result of constant

Advantages of Deep Ploughing.

PUNT PLOUGHING TACKLE AT WORK. *(Photo, Messrs. John Fowler and Company.)*

Where drainage or irrigation canals can be made to serve as headlands, ploughing engines are sometimes carried in suitable punts.

trampling. It is estimated that horses make a footmark on every square foot of land turned up by them. The hard "pan" thus created prevents roots penetrating to the subsoil, and also holds up surface water in wet weather. Deep ploughing, conducted at high speed, pulverises the land, opens up the subsoil, and allows both roots and moisture to find their way downwards easily. In the case of a long drought, deeply ploughed ground acts as a natural reservoir, and supplies the growing plants above with moisture long after shallow ploughed ground would have been parched up.

The most highly developed engines used for ordinary cable ploughing are compound, have steam-jacketed cylinders, a two-speed travelling gear, and, if required, two speeds on the ploughing gear They can be adapted to burn oil, fuel, or straw in countries where these fuels are more economical or more easily obtained than coal. The winding drum is usually carried under the boiler on a vertical axis ; for special purposes it is set vertically at the side, as shown in one of our illustrations. In addition to its agricultural duties, the ploughing engine serves as an ordinary tractor, and to work threshing, chaff-cutting, and other machines.

Ploughing Engines.

Coming now to the implements required for cultivation, we may begin with the ploughs. These can be classified under two headings—the *balance* * and the *turn-round*.

* Despite its name, Messrs. Fowler's balance plough is fitted with a gear which automatically moves the carriage forward of the centre of gravity, whichever way the plough may be travelling, so as to concentrate more than half the weight on the shares in work and prevent any tendency to jump.

Two Types of Plough.

The first of these is distinguished by two sets of shares mounted on frames set at an obtuse angle to one another in the vertical plane fore and aft. From each end of the plough a cable runs to an engine. The end to which the pull is imparted falls and engages with the ground, raising the other, or free, end into the air. The shares are so arranged that whichever set of shares may be working, the furrows shall be turned over in the same direction. This type of plough is most commonly used on land which has been under cultivation for some time for cereal and root crops.

A BALANCE DISC PLOUGH TURNING IN A GREEN CROP.
Observe the forward (idle) limb projecting upwards.
(*Photo, Messrs. John Fowler and Company.*)

The turn-round plough also has two sets of shares, but in this case they are both arranged behind the supporting wheels. When, on reaching the end of a bout, the plough gets the pull of the engine on the other side of the field, it rotates through half a circle, automatically raising one set of skives and mould boards and depressing the other.

A "RIDGER" AT WORK.
(*Photo, Messrs. John Fowler and Company.*)

For ploughing in green crops discs can be substituted for the skives and mould boards of either type.

Special Ploughs.

Subsoil ploughs are fitted with tynes behind the plough bodies to break up the land below the furrow without bringing it to the surface, and so to improve the drainage while increasing the moisture-retaining capacity of the soil. For breaking up land for the cultivation of sugar-cane, beet, tobacco, and vines, and for preparing heath for afforestation, special ploughs are made, their strength being proportionate to the exceptionally heavy work which they have to perform. It is interesting to note here that the afforestation of thousands of acres of waste land has become possible only through the agency of the steam plough. The following passage from the *Breslau Morgen Zeitung* describes graphically

A HEATH PLOUGH BREAKING LAND FOR AFFORESTATION.

the behaviour of a Fowler trenching plough in an area of suburban land broken up for tree planting :—" The ploughing of this land presents considerable difficulty, as at about the middle of the land in question there is a vein of bog iron-ore running from east to west. In the southern part, with its light, sandy soil, the plough makes its deep furrow without difficulty, but in the middle the steel shares begin to creak and groan. The plough only moves forward by fits and starts. But the engine power conquers the elementary power of the ore veins. The stones break with a crash, and are slowly but surely forced out of the upper edge of the furrow by the mould board. Colossi of from 1,100 to 1,650 lbs. weight are then thrown up like mere sods. Only engines of powerful build and solid construction can perform such a task. The trench is made quite smoothly, and the whole work proceeds so noiselessly that the humming and puffing of the working engine can scarcely be heard."

Very Hard Work.

By means of the same, or a somewhat similar machine, marshy land may be drained and rendered fit for cultivation. About ten years ago an Algerian swamp, once a favourite resort of sportsmen, and also a source of malarial fever, was thus converted into vineyards or corn land. The task of effecting the drainage was extremely difficult, as the ploughs sank repeatedly into quagmires, and special causeways had to be constructed to bear the engines ; but eventually the land was deprived of its surplus moisture, and, by a succession of operations, made to produce fine crops of grapes and corn. It is certain that such work could not have been carried out by hand labour, except at a cost which would have deterred any one but a wealthy philanthropist from undertaking the enterprise.

Drainage of Swamps.

A particularly ingenious drainage machine, known as a " mole drainer," is used in a strong clay subsoil naturally impervious to water. The drain is cut by a vertical share carrying at its lower end a cylindrical body pointed off

The Mole Drainer.

A TRENCHING MACHINE.

One of these will make trenches up to 2 feet in depth and up to 3 feet in width.

(Photo, Messrs. John Fowler and Company.)

in front and drawing behind it, by a short chain, an egg-shaped tail which consolidates the sides of the drain. This machine proves most effective in land which has a slight natural slope. If no suitable ditch exists already, a main drain is dug by hand along the lower side of the field, and at regular intervals on the uphill side of the drain are cut small excavations, called "eyes," to act as starting-points for the mole drainer. As it approaches the uphill boundary the mole is raised gradually to the surface by means of self-acting gear. When the drain cutting is complete, the eyes and main drain are filled in with tiles. The surface water finds its way down through the vertical slits cut by the share into the "mole runs," and by them is carried to the main drain. In very stiff land the drains cut by the machine will keep open for more than twenty years. Even if the operation has to be repeated at lesser periods, the accumulated cost of several repetitions is much smaller than that of laying pipes, and is much more effective.

A MOLE DRAINER, WITH TYNE AT WORK.

After the ploughing, the seeding. Machine drills have—in highly civilized countries, at any rate—entirely superseded broadcast sowing of corn and small seed by hand. The machine does its work with a regularity that cannot be approached by human agency. Special devices are used for planting beans and potatoes. The bean planter drills a hole, drops in a bean, and covers it up. The potato is treated in a similar manner, after having been cut up into halves or quarters, if the farmer so wishes. Then there are the machines for setting young plants, for weeding, for loosening or gathering root crops, many of them so exact in their operation that they seem almost to be endowed with intelligence.

Seeding and Planting Machines.

Next we come to the reaping machines, which are perhaps the most interesting of all agricultural implements. Though on many farms, especially on small ones, the horse-drawn plough is still used for cultivation, when it comes to reaping the primitive scythe and sickle are employed only when conditions prevent the employment of a machine.

Reaping Machines.

Almost eighty years have now passed since Cyrus H. M'Cormick, the son of a Virginian farmer, produced his first reaper with a many-bladed cutter bar vibrated rapidly to and fro between steel teeth by gearing driven off the ground wheels—such as is still used for mowing hay. The Hussey reaper, a somewhat similar device, appeared a couple of years later, and for a decade the two rivals competed against each other in all parts of the States. Then M'Cormick developed his device a stage further by adding a platform to catch the grain until sufficient had been collected to form a sheaf, when it was swept off by a rake. The inventor received special recognition at the Great Exhibition held in London in 1851, as one who had done signal services to the cause of agriculture. Yet farmers, notoriously conservative as they are, looked askance at the invention, although its efficiency was demonstrated under their very eyes. As they could not understand it fully, and it was so far in advance of any mechanism

A HARVEST SCENE IN THE BIG BEND COUNTRY, WASHINGTON.

The headers are pushed by a team of horses and deliver the cut grain direct into wagons.

A THRESHING SCENE IN THE SALT RIVER VALLEY, ARIZONA.

The straw and chaff are blown through the long spout seen, on to a heap.

to which they were accustomed, they suspected it of being unreliable.

But in due course the machine attained a state of perfection which established its value beyond dispute. The self-binding apparatus, which passes twine round the sheaf, knots it, and cuts it off, was added, so doing away with the labour of the three or four men who formerly had followed a reaper to tie up the grain which it discharged. From that time onward the importance of the reaping-machine has increased. Vast numbers of machines are manufactured annually for use in all parts of the world.

The Self-binder.

What the self-binder is to the reaping-hook, the modern threshing-machine is to the old-fashioned flail. The corn, fed in through an opening in the top, is caught by a fluted drum and rubbed between it and a breastwork, which knocks out most of the grain, and flings the straw forward on to a series of shakers. These move the straw slowly towards the open end of the machine. Pieces of straw and any stray grains, seeds, or husks that escape the drums fall through the shakers on to sieves, and by them are fed to the blowers, which blow away the short straws. The grain, husks, and dust are then subjected to further winnowings, and finally the grain and seeds only remain to be dealt with. A series of sieves effects the separation, allowing the seeds and very small grains to pass, but retaining the good grain. The last reaches an elevator, which, by means of an endless band of cups, whisks it up to a hopper. From the hopper it falls on to another series of screens for a final winnowing, and thence passes into an inclined rotating cylindrical screen. This screen is divided into two sections. The first section has its wires set close together. The smallest grain, the "thirds," escape through it into a hopper and so to a sack. The "seconds" are freed by a second section, and the "firsts" drop out of the end of the screen. From start to finish the processes are purely automatic.

The Threshing-machine.

COMBINED HARVESTER AND THRESHER AT WORK IN THE BIG BEND COUNTRY, WASHINGTON.

The sacks seen in the foreground have been filled with grain and dropped by the machine.

A HUGE HEADER AND LOCOMOTIVE.

This outfit reaps and threshes the grain from ten acres in an hour.

A STEAM HEADER MAKING READY.

This view shows some of the gearing which drives the wheels, and also the large water tank used for supplying the boiler.

One might expect that farmers would be satisfied with reaping and threshing machines as separate units. Both are wonderful savers of time and labour. But the development of new countries and the occurrence of special conditions have given rise to fresh needs. In California, and in some parts of Canada, where vast areas are devoted to wheat, and where the weather conditions are very reliable, the crops can be left standing until so ripe as to allow threshing to follow immediately after reaping. There is no need for the grain to mature in the shock or stack. Advantage has been taken of this. Inventors gave their attention to producing a type of machine which should thresh and sack as well as reap the crops as it travels. The machines were of great size, requiring twenty or more horses to draw them; and their dimensions increased until it became common to encounter a "header"—these machines cut the ears off with as little straw as possible—having from thirty to forty mules harnessed to it. In fact, there are instances on record of as many as fifty mules being hitched to a single harvester.

Mammoth Reapers.

Finally, animal muscular strength was replaced by steam. An ingenious inventor devised a monster steam engine which could do the work of a hundred mules, and move a harvester of truly mammoth dimensions. One of the largest machines can cut a swathe 52 feet wide, and cover 100 acres in a ten-hour working day. (The record at present stands at 130 acres.) All the wheat growing on this enormous area is cut, threshed, and sacked by the header in one continuous operation, which means that from 1,400 to 1,800 sacks of wheat are made ready for market by a single mechanism between sunrise and sunset.

The illustrations which we reproduce of one of these giants may inspire the reader with a desire for further details. The machinery of the tractor is supported on three great wheels, having tyres five or six feet in width, so wide as to give the wheels the appearance of enormous steel barrels. The driving-wheels are operated through huge chains, with links of steel a foot long, and an inch thick, each tested to withstand a pull of 250 tons.

The Locomotives used.

The other parts are proportionately huge and strongly made. A tractor consumes six tons of coal and fifty hogsheads of water per day. In spite of its bulk it is easily handled. One man steers; a second stokes the furnace; a third operates the levers of the cutting-machine; and a fourth ties the mouths of the bags before they drop to the ground, to be picked up by the wagons drawn by other tractors, which carry them away to the railway. Following the grain to the end of the chapter, we see it raised by machinery into the bins of an elevator, automatically sorted, and weighed. Machinery delivers it to and removes it from a vessel that bears it across the ocean; machinery grinds it into flour, and mixes it with water and yeast for the baker's oven. It is not going beyond the truth to say that much of the wheat which

C.P.R. GRAIN ELEVATOR AT ST. JOHN'S, NEW BRUNSWICK.
(Photo, by courtesy of the Canadian Government.)

A GREAT 25-FURROW GANG PLOUGH, PULLED BY A STEAM TRACTOR, AT WORK ON A BIG CALIFORNIAN RANCHE.

we consume has never been touched by human hand until it comes from the oven as bread or pastry.

To revert for a moment to the great steam tractors described above. These find employment in operations other than reaping.

Tractors for Ploughing.

The American farmer works his outfit for all it is worth. So, when the sowing season comes, he hitches to his tractor a twenty-five-share plough; behind that in succession a number of harrows, a drill and seeder, and other harrows. In this way the land is ploughed, pulverised, and sown as fast as the machine can travel. We can hardly expect to see labour-saving developed further, so far as agricultural operations are concerned.

The direct ploughing system, in which the engine travels ahead of the plough over the land to be cultivated, is not practicable in this country with very heavy locomotives, the cable system being found much more effective. This does not signify, however, that direct cultivation by power is not practised,

Agricultural Motors.

as in recent years the light petrol or paraffin internal combustion tractor has obtained recognition among farmers for ploughing, reaping, threshing, chaff-cutting, etc. The weight of the agricultural motor being under two tons and distributed over broad wheels, the pressure per square inch on the ground at points of contact is actually less than that of a horse's hoof. A two, three, or four-furrow plough, according to the nature of the soil, is hauled by the motor, which is able to turn in a small circle, and so is as handy on the headlands as a team of horses. One form of motor plough has a double set of shares, arranged on the same principle as the cable-hauled balance plough, so that the direction may be reversed without turning round the machine. This plough is furnished with a light anchored cable which may be hauled on

IVEL AGRICULTURAL MOTOR DRAWING WAGON.

automatically if the driving wheels fail to bite, and so be made to take part of the ploughing strain. Under favourable conditions a motor plough can turn over from three-quarters of an acre to one acre of ground per hour, at a cost of about four shillings an acre for fuel, oil, wages, and wear and tear of machinery.

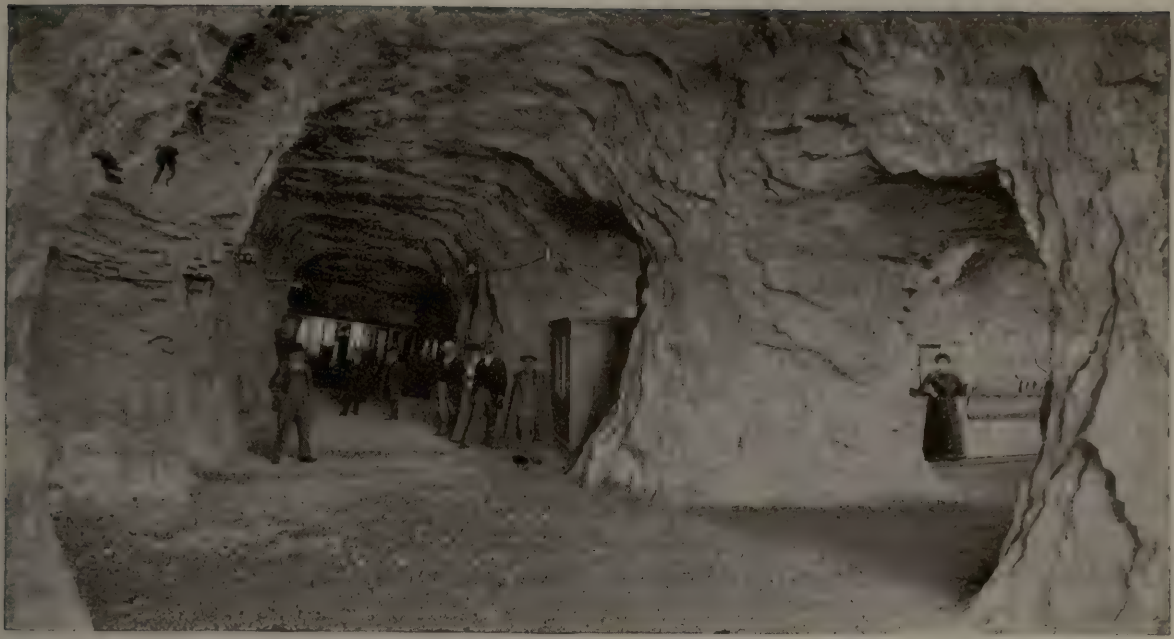
The Ivel agricultural motor (see illustrations) will draw two self-binders, each cutting a 6-foot swathe, and reap four acres in an hour. The angles of the standing crop are rounded off, so that the motor may travel continuously round and round the field. If occasion demands, the work can be carried on by night with the assistance of powerful headlights. By taking full advantage of fine weather in this way, the farmer improves his chances of getting in his crops in good order. In outlying districts, remote from a railway, the oil motor has a decided advantage over steam, in that its fuel can be carried to the scene of operations at a much lower cost. The farmer finds a machine of this kind invaluable. Besides ploughing and reaping his land it will thresh and grind the grain, cut the chaff, pump water, generate electricity, saw wood, and serve as a team of horses for hauling loads from place to place.

IVEL AGRICULTURAL MOTOR DRAWING SELF-BINDER.

[NOTE.—*Thanks are due for assistance given by Messrs. John Fowler and Co., and by Ivel Agricultural Motors, Ltd., in connection with the illustration of this article.*]

RUNNING DOWN TO SCHEIDEGG.

Observe the notched Strub centre rail and the four overhead trolley arms.



THE EIGERWAND STATION, JUNGFRAU RAILWAY. *(Photo, by courtesy of Swiss Federal Railways.)*

TWO REMARKABLE ALPINE MOUNTAIN RAILWAYS.

MANY probably have forgotten, and many more have never heard of, the first railway built over the Alps—the Fell Railway—which forty years ago climbed the pass of the Mont Cenis, and for three years carried the international traffic between France and Italy, and also the Indian mail, as regularly and safely as any of its present-day successors.

The Fell Railway.

This little line, with its 3 feet 7 inch gauge, was the pioneer of Alpine railways; and that its name is little remembered may be ascribed to the fact that it ceased to run in 1871, the year in which the Mont Cenis tunnel was opened.

Soon after the first appearance of the steam locomotive in France, engineers began to give attention to the apparently impossible task of linking up the railways on the north with those on the south side of the Alps. The different Alpine passes were studied carefully, and in 1840 it was decided to construct the Mont Cenis tunnel line. As we have noticed on a previous page (vol. iii., p. 149), actual work on the line did not commence until 1857, and at that time it was expected that twenty-five years might be consumed in boring the tunnel. So urgently was the railway communication needed that an English engineer, Mr. J. B. Fell, conceived the idea of carrying a railway over the mountain, for dealing with the traffic until the tunnel should be finished—or, if the tunnel proved impracticable, to serve as a permanent

Schemes for a Line over the Alps.

line between France and Italy. The line was to follow, more or less closely, the route of the existing road, which has a historic interest as having been completed by the great Napoleon, for military purposes, in the years 1800 to 1810, during his occupation of Piedmont.

The Mont Cenis Road.

To reach the summit elevation of 7,000 feet, steep inclines, with a maximum gradient of 1 in 10, would be needed; and as ordinary locomotives, depending for their adhesion on the weight carried by the driving wheels, would not be able to climb inclines of such steepness, Mr. Fell proposed to overcome the difficulty by using a system of his own invention. As the system is in use on the Snaefell Railway,* Isle of Man, and on a railway in New Zealand, it may be as well to describe it somewhat fully, using the present tense.

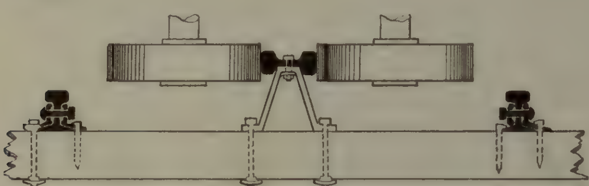


DIAGRAM SHOWING THE FELL CENTRE-RAIL TRACK AND GRIPPING WHEELS.

The Fell System.

The permanent way consists of ordinary cross-sleepers, carrying two track rails, between and equidistant from which is a double-headed centre rail, laid on its side and mounted eight inches higher than the ordinary rails, on steel chairs bolted securely to the sleepers. The locomotives are provided with four cylinders, one pair to work the vertical or carrying wheels, the other to drive two or more pairs of horizontal wheels, which, by means of a screw-gear, can be made to grip the centre rail on both sides with the force required by the gradient travelled over. Carriages are provided with horizontal flanged

A RADIAL FELL TANK ENGINE. BUILT BY MESSRS. NEILSON AND CO., GLASGOW.

wheels, having the flanges under the rails, which the wheels therefore cannot mount—an arrangement which, as events have proved, makes it practically impossible for locomotives or rolling stock to leave the track under conditions that, but for such a safeguard, would have disastrous results. Also it has been found in practice that where the centre rail is laid there is less friction, and consequently less wear and tear, on curves, as the horizontal wheels take the pressure due to centrifugal force and prevent the flanges of the carrying wheels grinding against the outer rail.

Safety Wheels.

For control purposes the ordinary brakes are supplemented on every vehicle by centre-rail brakes, worked by hand or by power. Two powerful steel jaws press cast-iron brake blocks against the rail so tightly that, if proper care be exercised, a train cannot possibly get out of control.

Brakes.

A locomotive incorporating the principles sketched above was built at Birkenhead, and tested on the High Peak Railway, Derbyshire, with results so encouraging as to justify application being made shortly afterwards to the French and Italian Governments for concessions to build the Mont Cenis Summit Railway.

The two Governments sanctioned the construction of the line on the condition that a trial of the system should be made on the

* In this case the system is not used for hauling purposes, but for safety.

mountain itself during the winter months, to test, with the greatest possible severity, the capabilities of such a railway.

Concessions granted for the Line.

A trial line, 1½ miles long, was therefore constructed on the zigzag known as Les Echelles, above Lanslebourg (see map), 6,000 feet above sea-level. The steepest gradient was 1 in 12; the sharpest curve had a radius of only 2 chains, or 44 yards. The experiments, carried out during the summer as well as the winter, were so successful that in November of the same year (1865) the French Government granted the concession from St. Miche. to the Italian frontier. The Italian concession was obtained in the month following.

The work of construction began in the spring of 1866. Leaving St. Michel, the line followed the valley of the Arc, utilizing the public road as far as possible, while allowing a sufficient width for the vehicular traffic. The valley was so narrow that the stream,

MAP SHOWING THE COURSE OF THE FELL MOUNTAIN RAILWAY FROM ST. MICHEL TO SUSA.

when swollen by rain or snow-water, sometimes carried away the track. From the almost perpendicular mountain-sides loose rock would occasionally be detached by the action of frost or water, and crash down, bringing with it tons of débris. As a protection against such destructive forces, screen-walls of masonry were built against the mountain-side.

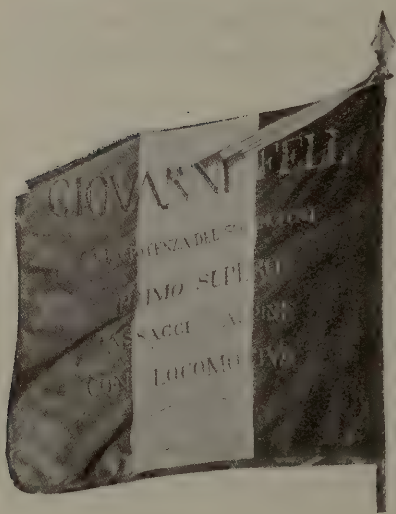
Construction begun.

THE MONT CENIS ROAD AT LES ECHELLES, ON THE FRENCH SIDE OF THE MOUNTAIN.

The Fell Railway followed this road for most of the distance.

At Modane the line deviated from the road, as the valley widened, and ascended by a steep incline to a higher reach of the river. Thence to Lanslebourg, the little frontier town which was made the headquarters for the upper section of the line, no great engineering difficulties presented themselves. But beyond Lanslebourg had to be surmounted the great Echelle, which, with its numerous twists and turns, made it difficult to lay out the line. The road was narrow, and the authorities required the rails to be placed on the outer or precipice side for the greater safety of the

Engineering Difficulties.



THE ITALIAN FLAG PRESENTED TO MR. J. B. FELL ON THE OCCASION OF THE FIRST TRAIN CROSSING THE MOUNTAIN, AUGUST 26, 1867.

The words, translated, are: "John Fell, who, by the power of his genius, was the first to overcome the Alpine passes with the locomotive."

vehicular traffic. As the curves at the bends were too sharp to allow the line to follow them, curved tunnels of two chains radius had to be driven to enable the track to step from one bend of the road to another. The road could not be widened, because one leg of a bend was almost vertically above the other; consequently the permanent way ran in places along the very edge of the precipice, and the sides of the cars actually hung over space, so that passengers could look down vertically into the valley 1,000 feet below. No wonder that some of the more nervous travellers closed their eyes as the train sped swiftly from curve to curve, swaying ominously now to the right, now to the left.

After crossing the frontier the line descended to the Italian zigzag, which it did not follow, as a disused road was found to give better gradients, though a route more subject to avalanches. From the zigzag to La Grande Croix the track was very exposed to storms, and if not so snowbound as the northern side, was equally difficult to work in winter.

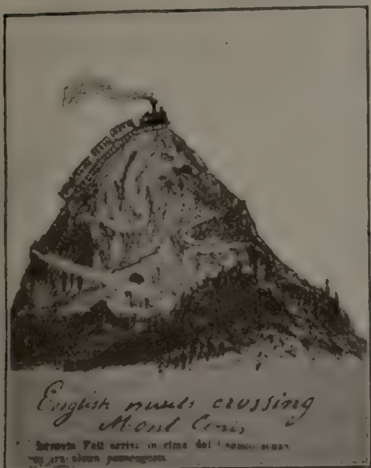
At Susa, 50 miles from St. Michel, was met the Haute Italie Railway, which runs down the valley of the Dora Riparia and terminates at Turin.

The Line completed.

By the end of 1866 good progress had been made with the works; but, unfortunately, the ensuing winter was very severe. Work was extremely difficult, the cold even on the lower parts of the line being so intense that earth-cuttings and the very holes for post and rail fencing had to be blasted. Next spring matters became still worse. Floods, the most serious that had occurred for more than two centuries, carried away over three kilometres of newly constructed line between St. Michel and Termignon, destroyed three bridges, and stopped work entirely on the French side. But despite all these misfortunes the last rail was laid on August 15, 1867, and the first train to cross the Alps ran from St. Michel to Susa on the 26th of the same month, so establishing a record in mountain engineering.

Its Short but Useful Life.

Difficulties were not at an end, however, for the French-built locomotives proved defective. The necessary alterations delayed the formal opening of the railway till the next year, when—on June 15—the ceremony was performed amidst great rejoicings. As already noticed, the railway served as the chief artery of east-bound traffic for the following three years, carrying passengers, goods, and mails with great regularity, considering the altitude of the line and the consequent climatic difficulties to be overcome. The crossing of the mountain was performed in four and a half to five hours, including stoppages for customs, etc., and on several occasions time lost by the Indian mail between Calais and St. Michel was made up on the summit railway. The safety of the centre rail system is attested sufficiently by the fact that not one of the 150,000 passengers who used this railway received the slightest in-



REPRODUCTION OF A COMIC SKETCH ISSUED WHILE THE FELL RAILWAY WAS IN OPERATION.

Underneath are the words, "The Fell Railway (train) arrives at the summit of the Mont Cenis without spilling any of its passengers."

jury. Among the passengers was our present King, who wrote of the line that it seemed to be the safest that he had ever travelled upon.

Naturally, at such an elevation provision had to be made against interruption by snow, and this was effected by means of covered ways of wood and corrugated iron, or, where there was danger of avalanches, by artificial masonry tunnels built against the side of the mountain. Altogether the line was thus protected for a distance of about nine miles.

Economy of the System.

The line ceased running, in accordance with a stipulation in the concessions, when the great tunnel was opened in September 1871; but not until it had so fully justified itself as to make many people in Italy think that, had Fell's system been developed sooner, it would, on account of its far smaller constructional and working costs, have prevented the tunnel scheme maturing. Had the summit line become a permanent one (which could have been done at a further cost of about £500,000), and improved in the matter of widening the gauge, reducing curves, using more powerful locomotives, and modernizing the working, there is little doubt that the summit line would have been capable of maintaining as good and efficient a means of communication as is afforded by the existing tunnel. The cost of working the line would naturally have been greater, but if this cost were capitalized, the total

VIEW OF THE MÖNCH FROM THE ENTRANCE OF THE SHORT TUNNEL BETWEEN SCHEIDEGG AND EIGERGLETSCHER STATION, JUNGFRAU RAILWAY.

THE JUNGFRAU RAILWAY APPROACHING THE EIGER.

capital for the summit line would be but £1,650,000, as against £5,300,000 for the tunnel.

It is interesting to notice here a present-day project for making a Fell-system railway over the Monginevra Pass, from Oulx to Briançon, to place Turin and all the northern part of Italy in direct communication with the south and east of France and with the port of Marseilles. This important object will be effected by a mountain railway a little more than 25 miles long, at a cost of about £660,000. The summit-level of the pass is 6,061 feet above the sea, and if the extra cost of working over this altitude, as compared with that of a tunnel, be capitalized and added to the cost of construction, the outlay will still be less than one-half that of a tunnel railway. The passage of the mountain will be made in less than two hours, and as there will be no difficulty in running as many trains upon this as on the existing Mont Cenis line, the traffic-carrying capacity of the Monginevra will be equal to that of Mont Cenis.

Project for another Pass Surface Railway.

THE JUNGFRAU RAILWAY.

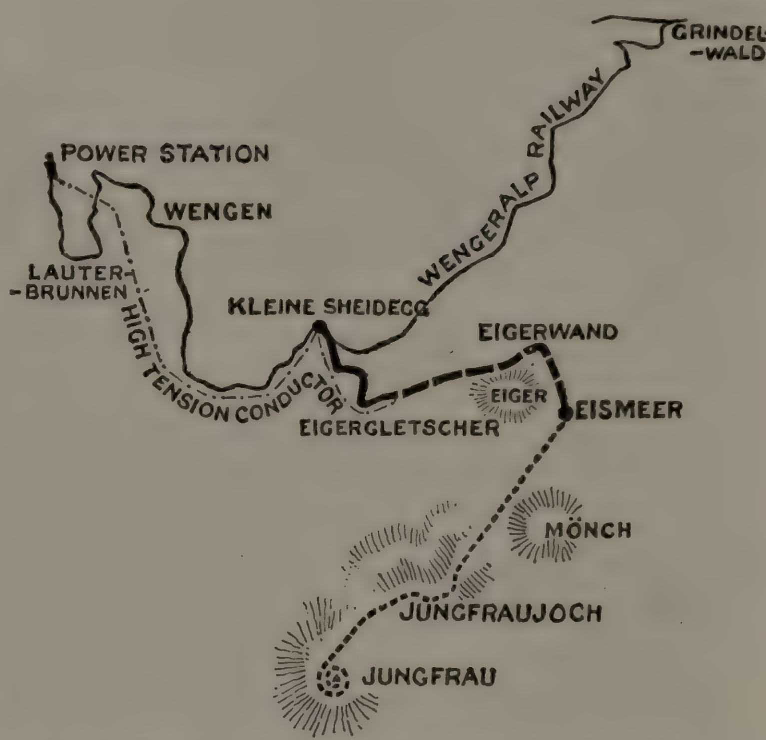
We now pass over some forty years to the construction of the latest addition to the many peak-climbing Swiss rack railways — that which ascends from Kleine Scheidegg on the Lauterbrunnen-Grindelwald or Wengeralp track to Eismeer station, cut in the rock of the western face of the Eiger, at an elevation of 10,368 feet above sea-level. Ultimately the rails will be carried within 300 feet of the summit of the Jungfrau, the most beautiful of the Swiss mountains, and a lift will transfer travellers to the topmost point of the peak to enjoy what has been pronounced the finest view in the world.

A Railway to a Mountain Peak.

Three schemes for leading a rack railway to a spot still accessible only to the practised mountaineer were first mooted in 1890, and were all shelved by the Swiss Legislature. Three years later M. Adolph Guyer-Zeller, a Zurich manufacturer, propounded a plan for making use of the recently opened Wengeralp Railway, referred to above, as a means of approach, and for constructing from Scheidegg a track

The Scheme.

on a maximum gradient of 1 in 4 along the sides of the Eiger, through the Jungfraujoch, and round and up the Jungfrau, stations to be made on the south and north sides of the mountain chain to afford a number of different view-points. The stations, constructed and projected, are seven in number, as follows: Kleine Scheidegg (6,770), Eigergletscher (7,620), Rothstock (8,300), Eigerwand (9,404), Eismeer (10,368), Jungfraujoch (11,139), and Jungfrau (13,664). The figures in parentheses signify their respective heights above sea-level.



MAP SHOWING THE WENGERALP AND JUNGFRAU RAILWAYS.

The completed portion of the latter's tunnel is indicated by heavy broken lines; the uncompleted sections above Eismeer by light broken lines.

A peculiarity of the line is that, when complete, only about the first 1¼ out of the 7½ miles will be in the open, all the rest being in tunnel.

A Railway in Tunnel.

The tunnel is 12 feet 2 inches wide and 14 feet 3 inches high, and has a semicircular roof. The rock through which it passes is for the most part a very hard limestone requiring no lining, so that the difficulty of boring was offset by the fact that a minimum of boring need be done. By keeping the railway under cover, entire protection was afforded against avalanches, and the miners were enabled to work all through the winter season when tourist traffic had ceased. This system also made it possible to complete the railway in instalments, and to utilize the receipts from opened sections to cover partly the cost of those being bored.

The heavy gradient and a deficiency of water prevented the use of the Brandt hydraulic drill. The less effective but more handy Siemens and Halske electric drills, making about 400 blows a minute, have been employed exclusively. The current for driving them is derived from the power-house below Lauterbrunnen, where the White Lütschine River is harnessed to a number of turbines, which also supplies part (2,650 horse-power) of the motive power for the electric locomotives operating the line.*

Electric Drills.

The surveying of the course was necessarily very difficult, and occupied nearly five years. While it was in progress a start was made at Little Scheidegg on the track construction, and in August 1899 the Scheidegg-Rothstock section was opened. In 1903 tourists could travel up to the Eigerwand station; in 1905 to Eismeer. It is anticipated that in 1911 the Jungfrau peak itself will be reached.

The rack system used here is that invented by M. Emile Strub. The electric current con-

* A second power-station on the Black Lütschine develops 10,000 horse-power.

THE ENTRANCE TO ONE OF THE TUNNELS.
A GROUP OF MINERS.

ductor runs overhead on the arch of the tunnel, and is conveyed to a locomotive by four trolley arms, two per phase. Each locomotive has two 150 horse-power motors. Whether ascending or descending the speed is limited by automatic brakes to 5¼ miles an hour—not merely to

The Track and the Locomotives.

course of the journey. Soon after leaving Scheidegg the train enters a short tunnel, during the transit of which the electric lights are turned on automatically. From the upper end of this tunnel to the Eigergletscher station the open sky is overhead, and a splendid scene delights the eyes of the

Eigergletscher Station.

EIGERGLETSCHER STATION. THE SNOW-CAPPED JUNGFRAU IN THE BACKGROUND.

avoid accidents, but because a too rapid change of elevation might affect seriously the health of the passengers. Were the main current to fail, these brakes would not become inoperative, because current for working the brakes is generated by the weight of the locomotive itself. As a further precaution powerful hand-brakes are fitted.

The carriages are provided with large glass windows, which permit the full enjoyment of all views that present themselves in the traveller. At Eigergletscher station there is a comfortable restaurant with sheltered balconies on three sides. Around this building have sprung up a village of workmen's houses, engine-houses, and workshops, which form the base of operations for the winter work. In autumn all the winter's stores and materials are collected at the Eigergletscher, as the Wengeralp Railway trains cease to run at the end of October, owing to the heavy falls of snow which at times bury even the posts

THE GLACIERS BELOW EISMEER STATION, FROM WHICH TOURISTS DESCEND BY THE GALLERY SEEN ON THE RIGHT.

and conductors of the electric current supply, and break down the telephone wires. Access to the houses is gained through deep trenches which have to be cleared after every snowstorm.

Terrific Gales.

Even more trying to the "colonists" is the *föhn*, or icy south wind, the violence of which is such that no progress can be made against it. On one occasion, during the winter of 1905, a gale blew in the windows and one of the walls of the locomotive shed, tore away some of the electric wires, and removed the roof bodily. What became of the roof was never ascertained.

A furlong above Eigergletscher station the railway enters the great tunnel, the loftiest in the world. Twenty minutes of steady climbing brings us opposite Eigerwand station, which is reached from the tunnel platform by a lateral gallery 26 feet long and 20 feet wide.

Eigerwand Station.

The station is a cavern cut out of the solid rock, its roof supported by large pillars left standing for the purpose. It has a floor area of 2,370 square feet. In the north wall are a number of large apertures, commanding a wide view of surrounding peaks. Through one of these openings a searchlight of enormous candle-power, with a reflector $3\frac{1}{2}$ feet in diameter, at night projects its beams, which are said to be clearly visible at a distance of 60 miles, and to enable a newspaper to be read in the streets of Thun.

Three-quarters of a mile beyond the Eigerwand is the Eismeer station, the present

terminus, cut in the south face of the Eiger. Its elevation of 10,368 feet makes it the highest railway station in Europe and the highest of all tunnel stations. Here we find a large, comfortable room, parquet floored, containing a restaurant and a post-office. All heating and cooking is done here by electricity. In the outer wall are several windows commanding the broad slopes of the lower saddle of the Mönch. A long sloping gallery cut in the rock on a gradient of 3 in 10 leads down to the glaciers 130 feet below, and gives access to a great plain of eternal snow which affords a safe playground to devotees of winter sports.

Eismeer Station.

When it is finished, the Jungfrau Railway will represent a remarkable engineering achievement. Never before has a tunnel on a gradient of 1 in 4 been constructed at such an altitude. The engineers were unable to profit by previous experience gained elsewhere, and so had to invent devices to meet their special needs. As the tourist glides easily up the steep acclivities of the mountain, he might well spare a thought for the men whose labour and perseverance have made easy for him the way to one of the noblest of Alpine peaks.

[NOTE.—*Thanks are due to Mr. G. Noble Fell, A.M.Inst.C.E., and to the Swiss Federal Railways, for assistance given in connection with the letterpress and illustrations of this Article.*]

GREAT UNDERPINNING ACHIEVEMENTS.

BY W. T. PERKINS.

AS a rule the public knows little of the wonderful achievements of science in the field of what is technically known as "underpinning," a term signifying the substitution of new for old foundations or other supports of a building. Yet there is no class of work that involves more risk, and it is curious to note that, while superstructures are in the main raised from the designs of the architect, schemes of underpinning are very frequently entrusted to his companion the engineer. The author has selected three examples of work of this kind, each employing features of its own, and they may be regarded as representing the best devices of some of the leading modern engineers.

One of the most remarkable illustrations of underpinning is undoubtedly that which has recently been carried out so successfully at Winchester Cathedral. This venerable structure, situated at the bottom of a hill, near the river Itchin, is prominent among English cathedrals because of its great length.

Winchester Cathedral.

A few years ago, when the cathedral was being repaired by Mr. T. G. Jackson, R.A., the diocesan architect, in conjunction with Mr. J. B. Colson, the late architect of the cathedral, it was discovered that serious subsidences had occurred in various parts of the structure. The most alarming falling away, disclosed in the presbytery, amounted to nearly 2 feet 6 inches. Here the outer walls and their buttresses were considerably out of the perpendicular. The groined arches were distorted, and stones were occasionally falling from the roof, indicating that disintegration had actually begun.

Serious Subsidences of the Structure.

Sinking a trial pit some yards away, Mr. Jackson found under the clay a bed of peat eight feet thick, resting upon a solid formation of flint and gravel. Another excavation was made close to the south wall of the presbytery, and at a depth of about eight feet below the turf the bottom of the masonry constituting the foundation was laid bare. It was then ascertained that trees had been extensively em-

ployed in securing a foundation for the cathedral. Beech had been selected for the purpose, and the trees were placed side by side horizontally, a second layer being in some cases rendered necessary owing to the loose character of the soil.

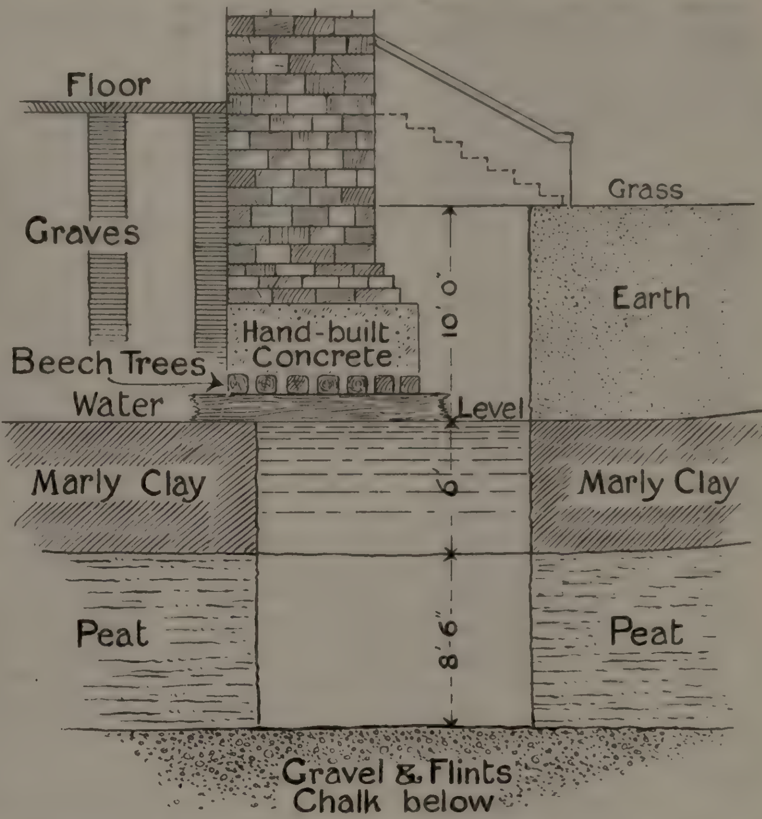


Diagram to show the work that had to be done by a diver under the walls of Winchester Cathedral—namely, to cut a series of pits in the clay and peat down to the gravel stratum, and fill in with concrete, bricks, and cement.

Their Cause.

Although seven hundred years had passed since these foundations were put in, many of the logs were sound at heart. Decay had seized others; but even where they had become rotten, owing to the water contained in the subsoil, the timbers had not been squeezed or flattened out by the superincumbent weight.

Underneath the logs was a bed of chalky marl, in certain places six feet thick. The peat bed seemed to be virtually impervious to water, but when the trial excavation had reached about a foot from the bottom of the deposit —the thickness ranging from 5 feet to 8 feet 6 inches—a volume of water burst upwards through the lowest layer, having made its way from the gravel bed below, into which it had flowed from the river Itchin.

Called upon to deal with a task which imperilled the very existence of the entire edifice, Mr. Jackson and Mr. Colson wisely summoned Mr. Francis Fox, of Sir Douglas Fox and Partners, to their aid. Every one could see that ordinary pumping operations would be futile, and it was equally certain that the use of compressed air could not be relied upon during the work of restoration. Screw piles and caissons were regarded as being also unsuitable, and resort to the expedient of constructing a slab of concrete under the cathedral was deemed undesirable. These different methods were discussed in turn, and all alike were rejected.

A Diver employed.

It seemed that none but a diver could do what was necessary to save the fabric from disaster. Mr. Walker, an experienced man employed by Messrs. Siebe and Gorman, was therefore engaged to complete the necessary excavation, which had to be made in water, and this he accomplished in lengths of five feet. An illustration shows the diver in the act of descending into fourteen feet of water.

Mr. Fox, an expert diver himself, donned the dress and made a careful examination of the solid strata under the peat bed. He was satisfied that the hard flinty gravel, resting as it did upon the chalk measure, offered an excellent material upon which to insert the new foundation that was obviously needed.

DIVER DESCENDING TO WORK UNDER THE WALLS OF WINCHESTER CATHEDRAL.

may help him to *pull himself down* step by step.

The pits which the diver had to dig were absolutely dark, owing to the fact that the water was much discoloured by the peat. Strangely enough, no means has yet been devised for introducing artificial light when work has to be performed under such trying conditions. The underpinning of Winchester Cathedral had therefore to proceed not by the aid of sight, but solely by a sense of feeling.

The Diver's Work.

When the diver removed the peat from each of the 5-feet beds in which he had to carry on his operations, he deposited bags filled with concrete, which were lowered from the scaffolding on the surface, where the air pump was kept in constant motion. Having been well trodden down all round, so as to present a flat surface, the bags were cut open by the heavy knife carried by the diver, and another layer of concrete bags was then laid in precisely similar fashion, the foundation in all consisting of four courses.

The engineer, wearing the diving suit, frequently inspected the work, and had the satisfaction of knowing that in each pit a bed of concrete as hard and solid as rock was formed. Water from the gravel was thus effectually shut out, and the excavation pumped dry. The concreting was continued, either in bulk or in block, until a considerable height had been attained. Blocks of concrete in some cases, bricks and cement in others, were next carried

The Diver's Dress.

It will perhaps surprise many people to learn that each of the boots which form part of the diver's equipment weighs, with its added sole of thick lead, no less than 20 lbs. On his chest and back are carried two other blocks of lead, 40 lbs. apiece. The helmet weighs 20 lbs., and altogether the diver bears a load of nearly 200 lbs. Yet such is the flotation power of water that he can descend a ladder only by placing his feet, not upon the rungs, but underneath them, so that the tread

up, and tightly pinned to the under-side of the masonry constituting the original foundations of the cathedral.

Examination proved that nearly every wall of the building rested upon the peat mentioned. The south transept was more than four feet out of the perpendicular. The most serious fact was that the cathedral was sinking, due to the further compression of the peat in those places where it had not been removed. Fillets of cement, known as "tell-tales," were placed across the cracks that could be noticed, so that immediate warning might be given of any further movement. Except in the parts already underpinned, these fillets were in many instances broken within three or four weeks. In fact, the cathedral was doomed unless it were underpinned, and that without delay.

At the invitation of the Royal Institute of British Architects, in February 1908, an extremely interesting account was given of this and kindred underpinning work which has been accomplished, and polished sections cut from one of the beech trees, labelled "Winchester Cathedral foundation, A.D. 1202," were exhibited. There are several other specimens from wooden foundations dated 1079, as well as one that goes back as far as A.D. 888. This last curious relic came from under the Campanile at Venice, and was presented to its present owner by Count Grimani, the sindico, or mayor, of the ancient city. All these specimens have been under water for centuries, and yet are as sound to-day as when they were laid by the early builders.

Holy Trinity Church, Hull.

Another striking example of underpinning is associated with the magnificent Church of Holy Trinity at Hull. One of the three largest churches in England, it consists of an unusually fine nave of eight arches on each side, with side aisles, choir of five arches and side aisles, transept, and a handsome tower in the middle, resting on four massive piers, each cruciform in plan. The total weight of the tower is 2,800 tons, so that each pier is called upon to support 700 tons. A period of more than two hundred years elapsed before the structure was completed. The foundations of the tower were laid soon after 1300, the choir was finished in 1361, the nave in 1418, and the upper portion of the tower in 1520.

A few years ago it became evident that the edifice was falling. Settlements had been detected in the arches and piers surrounding the tower. Considerable cracks resulted, and from time to time portions of masonry dropped. Matters became still more alarming when a large corbel supporting the ridge of the choir roof on the eastern face of the tower collapsed. Mr. F. S. Brodrick, the York diocesan surveyor, then consulted Mr. Fox, in connection with the difficult and delicate work of underpinning.

Each of the slender piers of the nave had imposed upon it a dead weight of 75 tons, and all were exhibiting serious deviation from the perpendicular, being as much as 6 or 7 inches out of plumb. It was, indeed, evident that the tower was sinking slowly. A tradition existed locally that it rested on a timber raft, and careful examination proved the truth of the story.

Ominous Cracks.

The first step to save the church from the complete demolition of which it was in imminent peril was to strut and cross-brace the arches and columns, so as to prevent the possibility of a downfall during the process of restoration. In the next place the brickwork in the spandrels of the arches adjacent to the tower was minutely inspected, and when the plaster covering was taken away large cracks indicated that the brickwork was being dragged down by the pier. A hole was made in the floor of the church, and the timber raft was discovered. It rested upon clay overlying a deep bed of silt, and consisted of horizontal oak baulks, crossing each other at right angles.

Rot had reduced the upper layer of timbers to a powder very similar in appearance to coffee grounds, and the decayed material was full of what is commonly known as "eel-worms." Above these timbers the masonry was cracked and flaked in all directions, and it was apparent that an alarming state of affairs existed in regard to the whole of the foundation.

The problem of saving the edifice from ruin was hardly capable of easy solution. Pending a decision, the important preliminary step was taken of pumping cement into every cavity and crevice, as also into all the voids left by the decayed timber. To carry out this valuable work the grouting machine invented by the late Mr. James Greathead (see vol. i., p. 61) was brought into operation.

Beneath the nave columns vertical piles were found. It was supposed that these had been baulks of larch, but in some instances nothing except powder remained. The form of the original timber was seen impressed in the clay, but the wooden pile had completely rotted away, leaving only a cylindrical hole with the dust particles at the bottom.

At every step the utmost caution had to be observed, and the tower was dealt with pier by pier. In the first instance, on the east and west sides, quite clear of the pier, an excavation was made 24 feet long and 6 feet wide, extending to the same depth as the old foundation. The two holes, dug with the greatest possible care, were filled in with concrete, in which what are technically known as "grillage beams" were placed, with the object of distributing over the whole area of the new work the weight to be borne. A cavity 2 feet 6 inches deep and 9 inches wide was then cut or "jumped" through the lower masonry of the pier, and a steel girder, measuring 24 inches by 7 inches, was threaded through to rest on grillage beams in the concrete blocks.

Grillage Beams placed.

To prevent subsidence resulting from the deflection of the girder when it received its load, steel wedges were driven in under each end of the beam. Initial deflection was thus secured, and the further sinking of the pier became impossible. The girder was next built into position with blue brick in cement, and grouted up. Four steel beams were thus inserted in succession, and properly secured in like fashion. In this way the immense weight of the pier was quietly and safely transferred from the rotten timbers to the steel girders, resting on the thick bed of concrete. This work was accomplished in turn under each of the four piers supporting the tower.

The next endeavour was to get rid of all the old cracked masonry and decaying wooden beams at the base of the piers, some of the latter having been cracked through. It was not deemed safe to remove more than a fourth of these materials at once, and as the débris was cleared away the space was filled up with concrete in cement. The result of this splendid piece of labour is that to-day each pier stands upon about 560 square feet of solid concrete, instead of upon the old defective foundation, which would inevitably have involved a catastrophe of an appalling character.

Old Pier Foundations removed.

When once the piers had been rendered perfectly safe and sound, the task of taking down the defective nave columns began. One after another they were dismantled and rebuilt in a strictly vertical position, as much of the old masonry as remained available being utilized; but owing to the transverse strains that had been brought to bear upon the columns before the work of restoration commenced, two blocks out of every twelve on an average had been broken and rendered useless. Holy Trinity Church, Hull, was in this way saved in the nick of time, to the intense delight of the whole population.

The Church saved.

Only one railway station has been built under a church in this country, and that is the Bank Station of the City and South London Railway, the first electric line opened in the Metropolis.

Building a Railway Station under a Church.

The original City terminus of this Company was at the Monument, but when it was decided to make an extension to Moorgate Street, and thence to Islington (subsequently to King's Cross and Euston), a station near the Bank of England became imperative. Land in such a position has long been at what may be termed a fabulous price, and the only spot that could be discovered where the new station might be conveniently placed was below the Church of St. Mary Woolnoth of the Nativity, standing at the corner of King William Street and Lombard Street. At the beginning the directors offered to buy the church outright, and the price mentioned was sufficient to have enabled the trustees to erect several similar edifices elsewhere.

The church was erected by Nicholas Hawksmoor, a pupil of Sir Christopher Wren, and completed in 1727. Possessing characteristics which differ from those of every other church in London, the original bold and beautiful type it embodies has always been admired; but the congregation is now small. The authorities, however, declined the terms of the railway company, who had no alternative but that of asking their engineers to construct the station under the church.

A bold and singularly competent group of men were the engineers—the late Sir Benjamin Baker, Mr. David Hay, and Mr. Basil Mott—and they gave the most positive assurance that the task could be completed with-

ST. MARY WOOLNOTH—MAIN GIRDERS AND CROSS NEEDLE GIRDERS SUPPORTING A GROUP OF COLUMNS.

The ends of needle girders used for supporting the south wall are also shown.

out imperilling the fabric in the smallest degree. They were as good as their word; though the church was by no means so sound in condition as was generally supposed. Indeed, one of the engineers told the writer that he could have put his umbrella through the roof in several places. Nevertheless, twin

tunnels were driven for the rails laid just above the blue clay, at a depth of 110 feet below the surface; a large shaft containing five electric lifts was carried therefrom; and over all, a commodious station was built sufficiently close to the street level to be approached on either side by a separate short flight of stairs.

ST. MARY WOOLNOTH—OUTSIDE GIRDER IN POSITION FOR SUPPORTING SOUTH WALL OF CHURCH, FACING KING WILLIAM STREET.

The achievement was truly described at the time as "a marvel of engineering skill." It involved the removal of the old foundations and the substitution of others which, while providing for all the necessary works of the railway, were sufficient to carry the immense superincumbent weight without causing the slightest movement in the architecture of the church itself. For the purposes of this task the floor, the organ, and all the internal fittings were removed, while the carvings and decorations were temporarily encased in wood.

Four massive box girders of steel, each 53 feet long, were successively set on steel legs, resting on stanchions carried to suitable foundations. Each pair of girders was ranged longitudinally alongside the old foundation piers and arches, and then saddled with smaller steel needle girders let crossways through the common base of the four groups of columns carrying the roof.

Supporting the Column Bases.

When the column bases were pierced for this purpose, it was discovered that the piers, instead of being sound Portland stone through and through, as was supposed, were merely shells of the material, varying in thickness from 6 to 9 inches, the interior being nothing

better than poor red bricks, loosely jointed together.

Precarious as such underpinning must ever be, jerry work of this kind made the task of the engineers doubly difficult. In the circumstances it became necessary to place a continuous sheathing of steel joisting under the area of each base, so as to tie the loose mass of woodwork together, and distribute equally the weight upon the needle girders. This was a very tedious operation, as only a small part of the base could be dealt with at one time.

ST. MARY WOOLNOTH—CRYPT, SHOWING VIEW OF OLD FOUNDATIONS OF COLUMNS AND ARCHES SUPPORTING CHURCH FLOOR.

As soon as this portion of the labour was completed, the south wall, on the King William Street side, was pierced at intervals of about five feet. Strong needle girders were inserted in the apertures so made, one end resting on the solid stone at the outside, the other being tied down to one of the main girders supporting the columns. Sufficient of the inside of the wall was then cut away to allow the girder (built before the needles were fixed) to be slid into position, and to permit also of a 14-inch blue brick wall being made, carrying short lengths of bearing girders, which were wedged tight up to the needles. The object of this device was to reduce the overhang of the needles when the outer portion of the wall came to be cut away, as no reliance could be placed upon the old work.

Work under the South Wall.

When the inside girder was fixed, steel wedges and packings were inserted between the top of the girder and the needles, the wedges being driven up tight to insure that the whole of the weight was carried by the girder and the blue-brick wall mentioned. The girder was designed to sustain permanently only half the wall, and it was therefore assisted by timber packings below.

After the wall had been pinned up above the girder, and everything was made solid by grouting, the task of fixing the outer girder became comparatively simple. The outer half of the wall below the needles was cut away, and the girder, meanwhile built, was moved into position. Thus the whole weight of the south wall was received by the two girders.

The north wall on the Lombard Street side presented a much greater weight, and as the work of supporting it could not be undertaken from the outside, the method adopted on the south side was impossible. One main girder was accordingly designed to carry the entire weight. But as it could not be placed far enough under the wall to be in a position to do this, suspended needles were attached to support the outer part of the wall, their tail ends being tied down to one of the girders for supporting the roof columns. Needle girders were fixed just below the church floor level, and under cover of these the wall was cut away to allow the

Underpinning the North Wall.

girder to be fixed. When the wall had been securely pinned up above the girder, the suspended needles were put in one at a time, the intervening masonry being held up by cross steel joists placed on top of the needles.

In every case the deflection of the girders had been taken up by a system of folding steel wedges, which were driven up as the old foundations were cut away and the superincumbent weight taken by the girders. The success of the whole operation was ascribed by the engineers in a great measure to the fact that grouting under air pressure had been extensively employed, especially in filling up interstices between the girders and the old masonry.

The girders are supported on steel-work stanchions, resting on large bed plates formed of steel joists and plates laid on a concrete bed having a minimum thickness of three feet. Girders, stanchions, and bed plates were filled in solid with breeze concrete and grout; and to guard against any possible deterioration through neglect of future painting, all were further encased in the same material.

In this ingenious way the central structure of the church, weighing 500 tons, the south wall of 350 tons, and the north wall of 500 tons were successively brought to rest on seven main girders, each weighing from 25 to 30 tons—masses not easily handled in the very limited space available.

The station booking-hall is 55 feet by 40 feet, and when all the lifts are in operation 350 passengers can at the same moment approach or leave the railway. The whole work was carried out to the satisfaction of every one concerned, and when all was over the authorities of St. Mary Woolnoth offered to sell the church to the company!

[NOTE.—*Thanks are due to Mr. Francis Fox, M.Inst.C.E., and to Mr. David Hay, M.Inst.C.E., for assistance given in connection with the letterpress and illustrations of this article.*]

A MOTOR RACE ON THE BROOKLANDS TRACK.

LANCIA TAKING A CORNER DURING THE VANDERBILT CUP RACE, LONG ISLAND, 1905.

THE DEVELOPMENT OF THE RACING MOTOR CAR.

BY GERALD ROSE.

FEW persons probably, except the designers and drivers of the racing cars which compete in the great contests held from time to time upon the open highroad, realize the marvellous amount of care and thought which go to the successful production of such machines. By the plain person they are classed with the taxi-cab and motor 'bus as ordinary "motors," though some, perhaps, vaguely recognize their *métier* from the fact that the bonnet is large and the seats are small. Not unfrequently, indeed, one hears a passer-by dignify as a "racer" some inoffensive, low-powered touring chassis which is out on a test run, fitted with the meagre seating accommodation usually allotted to those unfortunates whose task it is to guide a car through its infantile maladies upon the road. But even the little crowd which has happened upon a real racing car, and which, after a furtive glance at the axle-caps, stands detailing history to the newcomers, often does not realize that the object of its interest has surely a worthy claim to be ranked as one of the most remarkable pieces of modern machinery devised by the mind of man.

Racing Cars.

An exaggeration ? Think the question out. Here is no engine bolted to a solid bed-plate, working under unchanging conditions ; no turbine, humming evenly in the twinkling engine-room as the bow-wave curls from the big liner's fore-foot ; no 100-ton locomotive, running to schedule in ponderous contempt of the endless miles of smooth shin-

What is demanded of them.

ing rail, stretching in perfect symmetry as far as the eye can see. Here the equation of success has two ever-varying quantities—the man and the open road.

For the racing car must cover the roads at a faster average than ever express train has need of; and it must work throughout at full pressure, devouring space on the level, pulling up with grinding brakes and skidding wheels at the corners, sliding precariously round, to jerk off again the moment the bonnet is straight, with never a respite for the engine or the driver from the ceaseless bumps and jars and jolts, the quick accelerations and abrupt slowings-down of four or five hundred miles. And these are the mildest conditions: if there be added a brutal, a "harsh" driver, the ordeal becomes doubly hard. Yet many a car of the present day can undergo six or seven hours of this racketing, and come out of the severest test of engine and gears which can be imagined as fit as it was at the beginning.

THE DE DION STEAM TRACTOR, THE FIRST CAR TO ARRIVE IN ROUEN DURING THE "PETIT JOURNAL" TRIALS OF 1894.

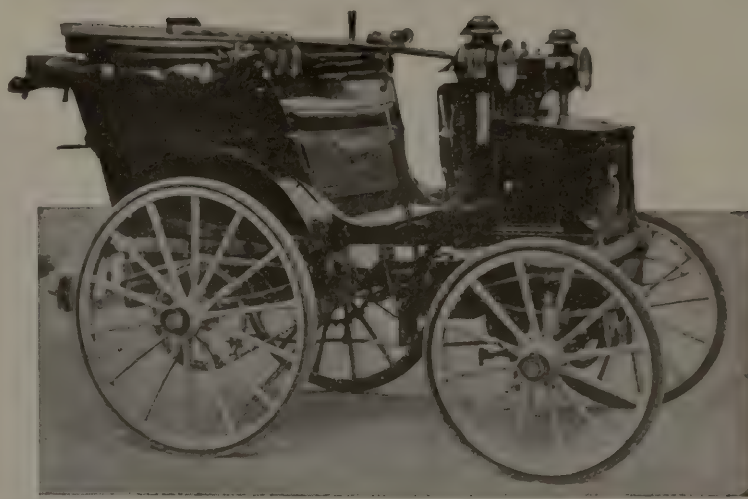
The Comte de Dion is driving.

Conceive it—a ton of machinery forced over the ordinary road at eighty, ninety, a hundred miles an hour, with nothing to lessen the road shocks except the tyres and the springs. To the driver the credit of holding the car to the road, but to the engineer the fame for building so marvellous a machine.

But it must by no means be imagined that motor races have always been a series of fierce struggles, or that racing cars have invariably been enormously powerful machines. In the primitive days of the motor vehicle the question was not so much whether the car would go fast as whether it would go at all; and the enthusiasts who entered for the competitions of the early period used the same machines that they drove about the roads for ordinary purposes. It is fifteen years now since the first important race was held for motor vehicles—though, strictly speaking, it was not a race, as the question of speed did not enter into the conditions. This was the Paris-Rouen trial, organized by the *Petit Journal*, which offered a number of prizes for the self-propelled vehicles that should best fulfil the conditions of being "easily handled, cheap to run, and without danger to the occupants." In those days the number of cars actually on the road was comparatively small; but the number of inventors beginning to take an interest in the subject was large, and consequently when the Parisian paper mooted the scheme the entries were numerous—in fact, reached the remarkable total of 102. But of this number very few can be considered as practical, being, like a large number of present-day aeroplanes, epoch-making successes—on paper. Some of the cars were stated to be

The first Important Race.

driven by levers, others by pedals. Several relied for their propulsive power upon the weight of the passengers—an arrangement which one can conceive as working admirably downhill, but which would seem insufficient under other conditions. High-pressure gas, pendulum, hydraulic, electric, and compressed air motors—all were represented, but the greater number of the entrants relied upon steam or petrol.



THE CAR ON WHICH LEVASSOR WON THE PARIS-BORDEAUX RACE, 1895.

Some preliminary runs were held as the date of the trials drew near, in order to discover if the cars were really capable of starting upon the trip to Rouen; for the organizers had no wish for a fiasco. Twenty-three cars in all received the official sanction, and of these fourteen were driven by petrol and nine by steam, all those relying on other motive agencies having failed to put in an appearance. The drive to Rouen was full of exciting episodes. Everywhere along the route the crowds thronged the roads, cheering the drivers and throwing bouquets at them—a disconcerting form of compliment which gave much trouble in the old days. Of the twenty-one starters, seventeen reached the finish, and the four which broke down were all steam cars. Nominally, it should be remembered, this was not a race; but there was, not unnaturally, a good deal of competition in the matter of speed, and the fastest vehicle was the De Dion steam tractor, which towed behind it a Victoria with the front part removed. This imposing machine covered the distance between Paris and Rouen—about 80 miles—at an average speed of $11\frac{1}{2}$ miles an hour; but the first prize was awarded to the Panhard and Peugeot firms equally, as the judges did not consider that the steam car was of the type they wished to encourage, a stoker being necessary as well as a driver. Drivers were scarce in those days, and there is an amusing story told concerning one of the steam cars, the stoker of which was at the back of the vehicle, and in communication with the driver by a speaking-tube. All things were apparently going smoothly, when suddenly came a message through the tube requesting an immediate stoppage. When the car had come to a standstill the stoker got out, and, complaining that he was too hot, announced that he intended to have a rest beneath the shade of a tree. The driver argued, expostulated; the stoker grew angry, and then and there resigned his position, leaving the driver in a quandary, as he could not proceed without skilled help. Fortunately at that moment another steam car drove up, and the driver, on hearing of the difficulty, lent a boy of thirteen, who made an admirable substitute; so the cars were able to proceed on their way to Rouen.

Paris to Rouen.

A Humorous Incident.

This trip was the virtual birth of the motor car, and from it dates the steady and unceasing development of the self-propelled vehicle, stimulated as it has been by the races organ-

A BOLLÉE RACING CAR OF 1898.

These machines were refused permission to compete in the race by the police authorities, but their drivers defied the regulations and went through the event. Standing by the car is M. Etienne Giraud, who used the vehicle in the general manœuvres of that year.

ized annually by the various automobile clubs, and in particular by the Automobile Club de France. That important body, however, did not come into being until the end of the following year, 1895, and was really the outcome of a committee formed for the organization of a big race from Paris to Bordeaux and back, a distance of some 732 miles. It was an ambitious scheme—a wild scheme, people said at the time. If it was difficult to get these machines to go for even twenty miles without a stoppage, how would it be possible to take them all the way from Paris to Bordeaux and back? But it was done; and M. Levassor, driving personally throughout the journey, covered the distance in 48 hours 48 minutes, at an average speed of about 15 miles an hour.

The Paris-Bordeaux Race, 1895.

His car was typical of the best design of the period. In its main lines it was remarkably similar to the cars of the present day, especially in the arrangement of the engine and gearing. It possessed a vertical motor in front, under a bonnet, driving through a clutch and a change-speed gear to a counter-shaft, on which was the differential (the device for allowing the back wheels to revolve at different speeds when rounding a corner), and thence by side-chains to the back wheels. If a modern chain-driven car be examined, it will be found that the main details are placed as in Levassor's No. 5, though naturally greatly modified and improved. But in many ways it differed from the luxurious carriages of to-day. The wheel-base was about 4 feet 2 inches (modern cars have a wheel-base of 10 feet and more), the wheels were large and solid-tyred, and steering was by lever, demanding the most careful attention to avoid accidents, and the highest speed on the level was about 20 miles an hour.

In the following year the committee, now formed into the Automobile Club de France, organized the great race from Paris to Marseilles and back, run out and home in ten stages. Thirty-two cars started, and after passing through the most extraordinary tribulations, due to a terrific storm which beset them on the second and third stages, fifteen reached Marseilles. It should be noted, though, that of these fifteen fourteen reached Paris again, so that the numerous failures were probably due in great part to the very unpropitious weather. The winning car, Mayade's Panhard, had a four-cylinder engine of eight horse-power, and weighed very much the same as the racing-car of to-day.

Paris-Marseilles-Paris, 1896.

Little change took place in the following year, and there was no race of any importance, so

that the next great event was the Paris-Amsterdam-Paris race of 1898. This was the first of the inter-country contests, and in some ways was considered as much a demonstration as a race. The most important innovation introduced was wheel-steering in place of the old and dangerous lever, which had been a fruitful source of accidents.

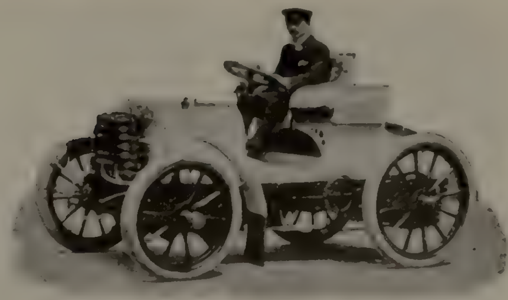
Paris-Amsterdam-Paris, 1898.

Charron had a four-cylinder motor of eight horse-power (but balanced, and therefore an improvement on Mayade's) on his car, and also used pneumatic tyres and a radiator of gilled tubing slung at the back of the car. His speed showed a considerable advance on previous records, being about 27 miles an hour over the 890 miles. This average was only slightly increased in the Tour de France, the great race all the way round France—1,350 miles—which was the chief event of 1899, though the winner, the Chev. Réné de Knyff, was driving a car of 16 horse-power. It was during this contest that Charron drove for 25 miles backwards, after breaking a part of the machinery which prevented him proceeding in any other manner—a performance which is said to have much astonished the spectators he met on the road.

Tour de France, 1899.

By this time the racing car was becoming a machine quite distinct from the touring car. The old saying, "The racing car of one year is the touring car of the next" held good until about 1904, and many an old racer has finished its life with a big *tonneau* instead of the two-seated body. But the speeds needed for successful racing were now so high that the machines used in the contests were of quite another build from their contemporaries which had a less exciting purpose. Early in 1900, Levegh accomplished an average of 51½ miles an hour between Bordeaux and Perigueux. None of the competitors in the first Gordon-Bennett race

First Gordon-Bennett Race, 1900.



CHARRON ON ONE OF THE 12 HORSE-POWER PANHARDS OF 1899.

These cars were the first with the radiator in front of the bonnet.

approached this speed, Charron, the winner, recording 38½. This, the first of the great international contests, was somewhat of a fiasco. France, Belgium, and America competed, the first-named with three champions, and the others with one each. The winner had at one time given up altogether, but finding that all the others were out of it except one, and that one a long way behind, he took heart again, and finished, though nearly placed *hors de combat* at the last moment by a large St. Bernard dog.

Racing-car construction was now advancing by leaps and bounds, and Fournier's Mors, on which he averaged 53 miles an hour from Paris to Bordeaux, was a machine very different from the Mors of 1899. A month afterwards Fournier repeated his success in the Paris-Berlin race, which was a duel between the Mors and the Panhard. Both these types were very heavy, and the authorities began to realize that the effect of allowing a free hand to the designers was bad, as they merely produced heavier vehicles each year. So for 1902 it was decided to restrict all cars to 1,000 kilos (or 2,204 lbs.). This led to a great improvement of the design, as the designers were compelled to find the solution of a problem which required the combination of the utmost speed with the greatest reliability for this given weight. It was at first thought that the result

Weight Limitation.

FLORAL TRIBUTES EN ROUTE DURING THE PARIS-BORDEAUX RACE, 1901.

would be a lessening of power and a gradual diminution in the size of the cars; but, on the contrary, the vehicles of 1902 were more powerful than any yet made, and in addition possessed many innovations which can only be attributed to the new weight regulation. The Paris-Vienna race of that year passed through Switzerland, the stages being Paris-Belfort, Belfort-Bregenz (this stage was neutralized, as the Swiss disapproved of the racing), Bregenz-Salzburg, and Salzburg-Vienna.

The Paris-Vienna Race, 1902.

Between Bregenz and Salzburg the cars had to pass over the Arlberg, a remarkable mountain climb which was full of trials for the cars and the men in charge. In the course of the 60-mile climb the road rose about 5,000 feet, and for the greater part was fringed by precipices, with nothing but small boundary-stones between the car and the drop. It is surprising that accidents were confined to a number of minor mishaps, but nothing serious. Marcel Renault, on a light car of his own construction, made the fastest time between Paris and Vienna, and the fact that his little 16 horse-power machine beat all the bigger racers is an eloquent testimony to the advantage of lightness on a hilly and rough road.

The Paris-Madrid race, consisting of that ill-starred dash to Bordeaux which will always be remembered on account of the many unfortunate fatalities which have to be recorded in connection with it, was the last of the great inter-country races—and in a way it can hardly be considered as an inter-country event, for the competitors got no farther than Bordeaux. At this period the cars had assumed very much the same appearance as that which distinguishes them to-day—long wheel-base, and a big bonnet housing a powerful engine giving abnormal speed. These two years, 1902 and 1903, may be considered the period in which the development of the racing vehicle was most rapid, a fact probably due chiefly to the weight limit; for the racers of 1903 are infinitely more like those of 1906 than the machines of 1899 resemble those of 1902. The

lengthened wheel-base and improvements in steering-gear made it possible to hold a machine on the road at speeds hitherto unattainable; and the increase in the power of the engines has never ceased, even in the days of cylinder bore restrictions.

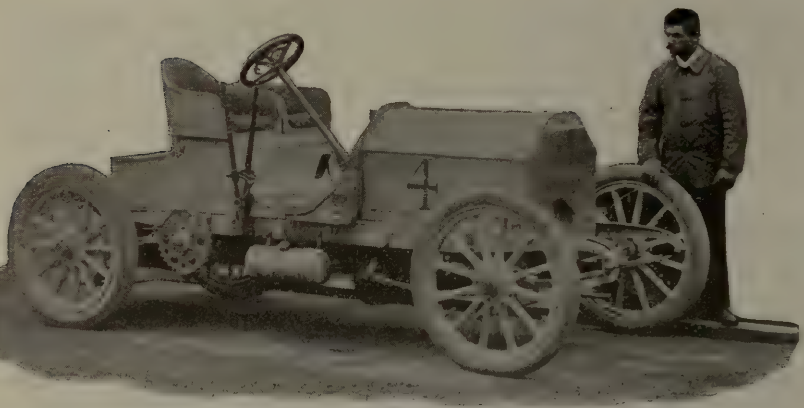
Tyres and Speed.

Gabriel, it will be remembered, won the stage to Bordeaux on his Mors with an average speed of some 65 miles an hour. It is said that he went through without changing a tyre, and surprise is sometimes expressed at this, in view of the multitudinous tyre-changes of modern days. But the reason—apart from the question of luck—is simple. For the first time the tyre manufacturers had overtaken the designers in the matter of speed. At first the cars travelled at a faster speed than the tyres would stand, and the drivers suffered greatly in consequence from bursts and punctures. But in 1902 and 1903 the standard of tyre resistance was higher than the strain of the speed which the cars could develop (except for very short periods downhill), and therefore the limit of tyre endurance was not reached. Thus Gabriel's car could probably not sustain a speed of 90 miles an hour for any length of time, the usual top speed being (in the race, not at a sprint meeting) in all probability 80 to 85. At this speed the tyres could hold out—and did so. Whereas in modern days, with maximum speeds of 105 or 110 miles an hour, the tyres cannot stand up under the stresses. From which it will be gathered that the designers have again outdistanced the tyre manufacturers.

Racing in Ireland, 1903.

The same freedom from tyre worries assisted Jenatzy greatly in winning the Gordon-Bennett race in Ireland in 1903; and it should be remembered that the car he drove was a stripped touring Mercedes of ordinary pattern, as the big 90 horse-power cars of that make had been destroyed by fire. Here again the comparatively low top speed was a great factor in the life of the tyre.

THE NAPIER WHICH WON THE GORDON-BENNETT RACE OF 1902.
In the car are Messrs. Edge and Napier.



THE CAR WHICH WON THE GORDON-BENNETT RACE OF 1903.

BARAS ON ONE OF THE DARRACQ RACERS OF 1904.

On this car he held for over a year the world's flying kilometre record, at the rate of 105 miles an hour. These were the first heavy racing cars built by the Darracq firm, and were not very successful in the long-distance races.

JENATZY ON A 120 HORSE-POWER RACER OF 1905.

The Cup having been won for Germany by Jenatzy, the Gordon-Bennett race of 1904 took place on a circuit starting from Homburg, in the Taunus. Jenatzy was on this occasion also the principal driver of the German team, and had a fierce duel with Théry, who won for France by about ten minutes. Of the two, the German car—a 90 horse-power Mercedes—was the more powerful; but Théry had a sympathetic and regular method of driving, which gave him the advantage over his rival, although the latter knew the course far better, having practised regularly for weeks beforehand. This practising has become a very important point in racing. When fifths of a second are valuable, it is of the greatest importance to know exactly the highest speed at which every bend and corner may be taken without disaster, and consequently the driver who knows his circuit by heart stands a very good chance in the race if his car is fast enough.

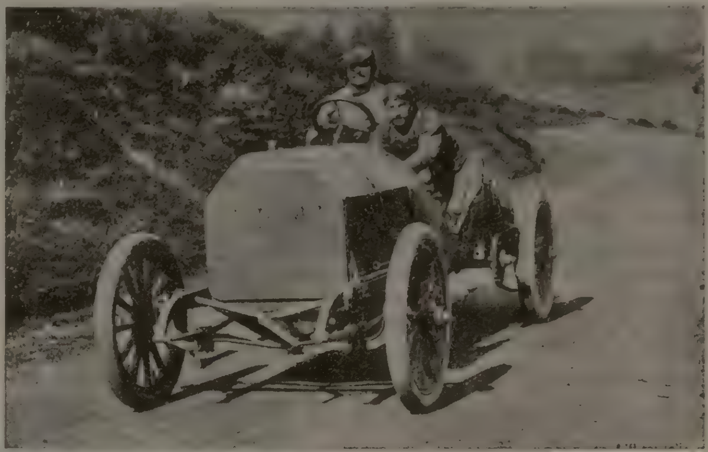
Practical Results of Racing.

At this point in the development of the racing vehicle the building of such cars became a science to itself. Abnormal speeds over long distances try the engines to the utmost, and it was found that it was no longer sufficient to put a powerful engine into a chassis that came just within the weight limit, and enter it for the great races. Such had hitherto been standard practice, but by degrees the manufacturers found that they

depended upon their racing cars for their reputations, and they therefore began to spend a great deal of time and money in perfecting their designs. This was without question good for the general standard of progress, but it involved a considerable disorganization of factory routine and a very large expenditure of money. Hence makers now began to object to racing.

The last Gordon-Bennett Race, 1905.

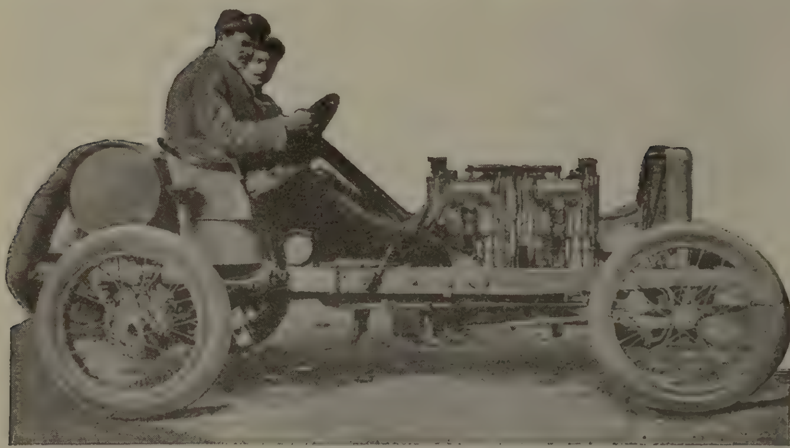
In 1905 the cars were designed to suit the circuit which had been chosen as the scene of the Gordon-Bennett—a circuit very different from the usual type, being full of bad corners and dangerous places. The cars were of very diverse types—some large, others comparatively small, like the Darracqs, which were amongst the most successful of the year. In one case an underslung frame was used, to obtain higher speed on the curves by lowering the centre of gravity; and in most of the vehicles great care was taken with regard to clutches and cooling systems—vital points on such a circuit. The French trials were won by Théry on a Richard-Brasier, which was one of the most moderately powered cars in the contest; and his subsequent victory in the Gordon-Bennett itself added the fourth successive win to the laurels of the famous Frenchman. This race at one time seemed to be in the hands of Lancia, who drove magnificently throughout the first two laps; but at the end of the third he damaged his radiator in some way, and was compelled to retire. This was the last of the Gordon-Bennett races, for the French decided not to compete again until the rules had been altered so as to give each country representation proportionate to its capacity for producing cars. With this end in view they substituted their Grand Prix, which was in 1906 a two-day affair, won by a Renault piloted by Szisz, who averaged about 67 miles per hour



LANCIA, THE HERO OF THE 1905 GORDON-BENNETT RACE.

These cars were amongst the fastest of 1905, and Lancia, after losing the Gordon-Bennett through a damaged radiator, subsequently lost the Vanderbilt Cup, when leading by a considerable margin, through a collision with a competitor.

JENATZY COMING UP TO TAKE THE HAIRPIN TURNING AT ROCHEFORT IN THE GORDON-BENNETT RACE OF 1905.



HÉMERY ON A DARRACQ OF 1905.

On this car he won the Circuit des Ardennes and the American Vanderbilt Cup. Wagner, on a sister machine, was at one time leading in the French Gordon-Bennett trials, but was hindered by tyre troubles. A comparison of this picture with the Darracq of 1904 shows the very great alteration in design made by M. Darracq.

during the first day, and covered the 770 miles at an average speed of 63 miles an hour.

A notable innovation used during this race—which, in fact, influenced the whole result of the Grand Prix—was the detachable rim. This enabled the driver (who, under the new regulations, was compelled to carry out all repairs and replacements aided only by his mechanic) to remove the rim and the damaged tyre simultaneously, and replace it by another rim carrying a fresh tyre already inflated. This reduced the time for a tyre replacement to about two minutes, whereas previously ten minutes had been considered very short time for the skilled racing mechanics to effect a change.

Detachable Rims.

After the big race another alteration of the rules was made, in which the important step of abolishing the weight limit was taken. Instead, a regulation was imposed restricting the fuel allowance of the Grand Prix cars to approximately $9\frac{1}{2}$ miles to the gallon, and by this rule it was hoped to limit the huge engines which had come into vogue during the last few years. But it certainly failed in its object, for so large an allowance permitted an engine of the same size as before, and only resulted in fine adjustment of the carburettor—in fact, the big race of 1907 was won by Nazzaro with an engine of the same size as

Limitation in Fuel.

THE THOMAS SIX-CYLINDER RACING CAR OF 1905.

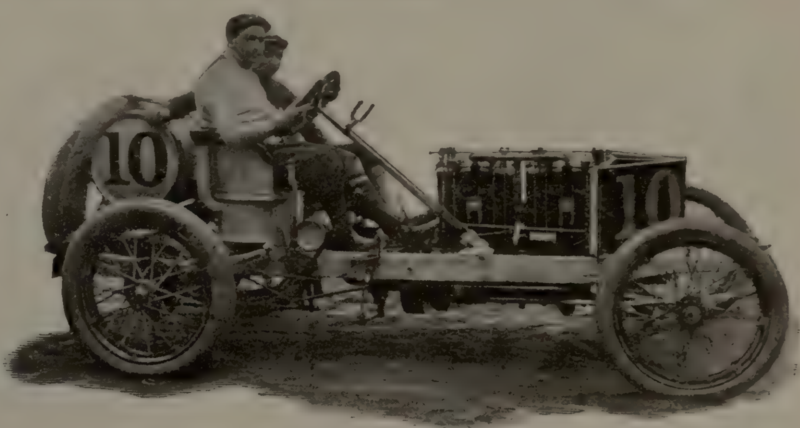
In this car the length of the bonnet was greatly increased by the position of the tanks, which were in front of, instead of behind, the driver. The latter, with the mechanic, sat behind the back axle.

that used in 1906, at an average speed of over 70 miles an hour. A few months later the rules were again altered, this time in a more practical direction, for the bore of the engine was restricted to 155 millimetres. As the ordinary engine of 1906 and 1907 had a bore of some 180 or 185 millimetres, this was a substantial reduction.

It produced some very notable results; for the bore having been limited, the stroke of the engine was greatly lengthened by some makers, and in some cases the power obtained far exceeded that which it had been the custom to expect from the racers of the former years. Certainly the Grand Prix cars of 1908 were the fastest road-racing vehicles ever produced, and caused an alteration of ideas concerning the high-speed petrol engine which can almost be called a revolution. In 1909 it had been decided to reduce still further the

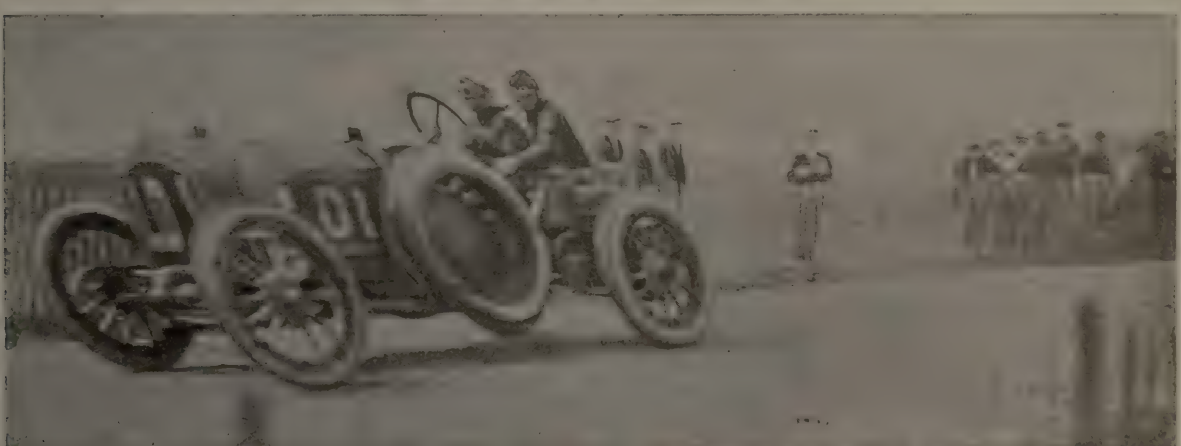
THE SIX-CYLINDER NAPIER OF 1905.

This car was the fastest English road-racer ever built, and still holds a number of world's records, made by Macdonald at Florida in 1905. It competed in the Gordon-Bennett race of 1905 in the Auvergne.



WAGNER, THE WINNER OF THE VANDERBILT CUP OF 1906, ON HIS SUCCESSFUL DARRACQ.

It is interesting to compare this car with those of 1904 and 1905. The change-speed lever was placed at the side instead of beneath the steering-column, and detachable rims were fitted.



DURAY AT FULL SPEED IN THE GRAND PRIX OF 1907, IN WHICH HE COVERED EIGHT LAPS AT AN AVERAGE SPEED OF OVER SEVENTY MILES AN HOUR.

GABRIEL, THE WINNER OF THE PARIS–MADRID RACE OF 1908, ON ONE OF THE 1908 GRAND PRIX CLÉMENT-BAYARD CARS.

These were very powerful machines, and about the fastest in the race.

liability which is a vitally important quality of the other. Here the machine is called upon merely to make a sprint of several minutes, and as long as it can keep up the required speed during one race it can be tinkered with before the next event. Nevertheless high speed at Brooklands is a very severe test of the solidity of a car, for slight inequalities in the track, unnoticeable at speeds below sixty miles

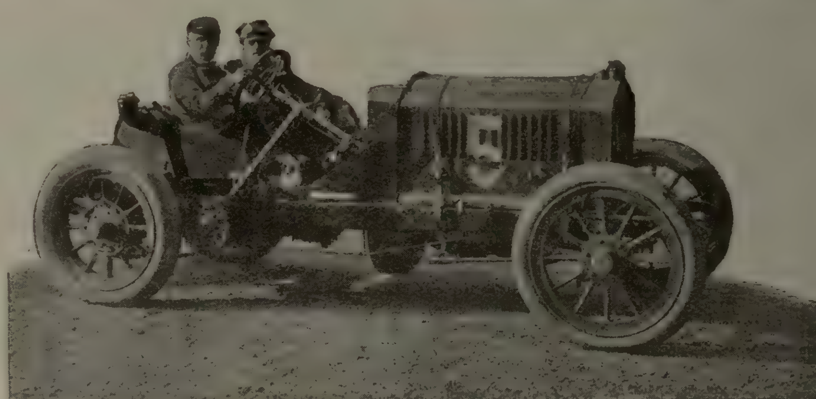
bore to 130 millimetres, and the minimum weight was also altered to 900 kilogrammes, but the prominent manufacturers decided to refrain from further racing, signing a bond to that effect. Consequently the race fell through, and no important event was held that year. This seems to have made an unfavourable impression on those who were responsible for it, as it is now proposed to hold the Grand Prix in 1910, but entirely without restrictions of any kind—a proceeding which is hardly likely to assist the progress of design.

AN ENGLISH RACING CAR.

Weigel on one of his own machines before the Grand Prix of 1908.

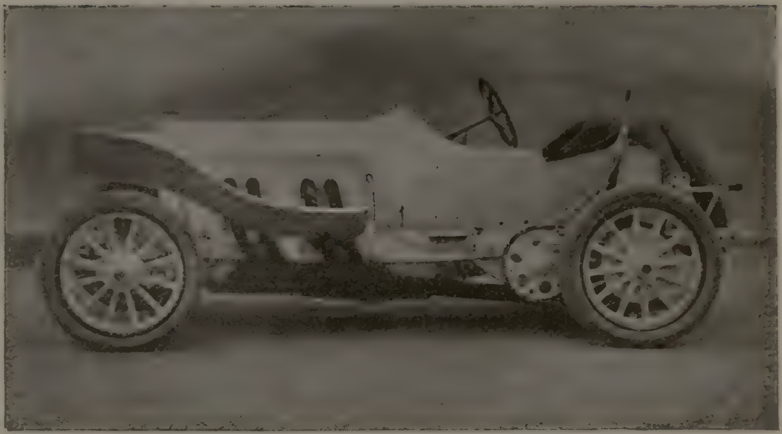
Track Racing.

Track racing is a branch of motor racing that has come into prominence of late owing to the opening of the Brooklands track, specially built for high-speed work, the banking being designed for speeds up to 130 miles an hour. This kind of work develops a car of a type totally different from the road racer, as the track car requires none of the re



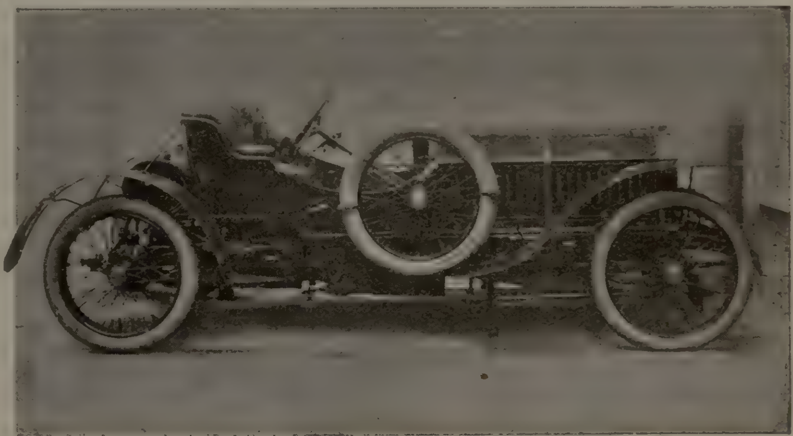
DURAY ON ONE OF THE 1908 GRAND PRIX DE DIETRICHS.

an hour, become formidable bumps when taken at high speed; and it is quite common to watch some driver who is going fast high up on the high banking, jolting far out of his seat as the springs work to their full extent. The most remarkable performance made upon the track is the record lap covered at the rate of 121·64 miles an hour by Nazzaro on Whit Monday, 1908, during the F.I.A.T.-Napier match. In this race the famous Italian drove a specially-built machine, with an enormous engine of some 180 horse-power, and in all probability the utmost speed of the car has yet to be recorded.



THE MERCEDES WHICH WON THE GRAND PRIX OF 1908.

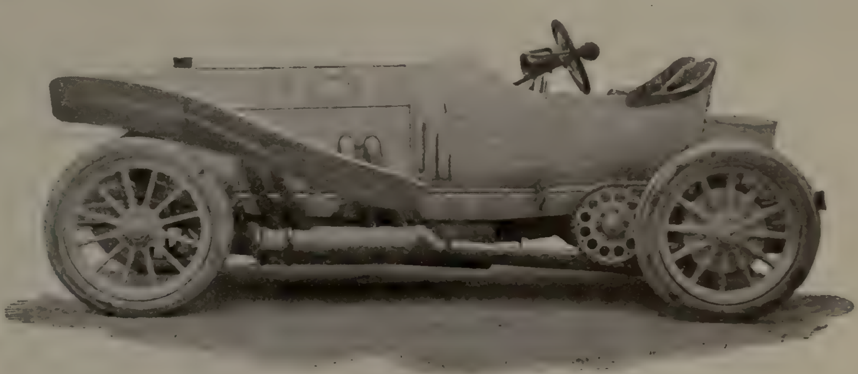
This machine represents the highest pitch of perfection in racing-car design yet attained. It ran without mud-guards in the race.



A RACING CAR DE LUXE.

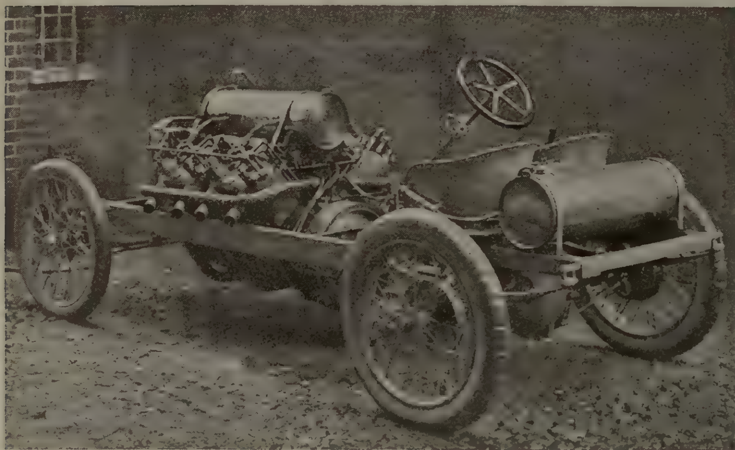
One of the Napiers built under the regulations of the Grand Prix of 1908. These cars had a remarkable system of rear-springing, which can be distinguished in the photo.

Track racing has always been very popular in the States, where the old trotting tracks are pressed into service —a most unsafe proceeding, as the surfaces are made of dirt, and the turns in many cases not banked at all. There have been many fatalities in consequence at American track-racing meetings, and the newly-opened Indianapolis course, which was designed for high-speed cars, has already a long list of casualties to its name. Such things, however, are of little account in the States, and the fascination of the track still holds good.



A BROOKLANDS MERCEDES.

A word should be said about the specially-built



THE 200 HORSE-POWER DARRACQ SPECIAL CAR.

This machine, which is the most powerful in existence, holds eight world's records, and has done 2 miles in $58\frac{4}{5}$ seconds. It is now the property of Mr. A. Lee Guinness. It is of the purest racing type, and has two speeds, 45 and 90 miles per hour.

Record-breaking "Freak" Cars.

"record-breaking" sprint machine. The first was probably Jenatzy's "La Jamais Content," an electric cigar on wheels, with which the impetuous Belgian established the flying kilometre record in 1899, at the rate of $65\frac{3}{4}$ miles per hour. Since that day many others have arisen, performed for a moment, and then disappeared, though the kilometre record has been held mostly by road-racing cars, it must be acknowledged. There were the Serpollets of 1901 and 1902, both strange-looking steam cars; Bowden's American Mercedes, with two 60 horse-power engines coupled in tandem, and a bonnet to match; the 150 horse-power Dufaux, the biggest engine ever put into a practical car; the giant F.I.A.T., already mentioned; and the remarkable machine which appeared in December 1905 — the 200 horse-power Darracq. This "speed-beast" broke the flying kilometre record forty-eight hours after it was finished, and subsequently at the Ormond-Daytona speed trials covered two miles in $58\frac{4}{5}$ seconds. Thence it passed into the hands of its present owner, Mr. A. Lee Guinness, who occasionally takes it to a meeting and sweeps the board.

PRINCIPAL TIME RECORDS TO DATE.

Distance	Time.	Average Speed.	Holder.	Where made.	Year.
	min. sec.	miles per hour.			
1 kilometre (flying start) . .	$17\frac{3}{4}$	125·9	Hémery.	Brooklands.	1909
1 kilometre (standing start) .	$27\frac{2}{5}$	81·6	Macdonald.	,,	1906
1 mile (flying start)	$28\frac{1}{5}$	127·7	Marriott.	,,	1906
1 mile (standing start) . . .	$37\frac{2}{5}$	96·3	Macdonald.	,,	1906
2 miles (flying start)	$58\frac{4}{5}$	122·4	Demogeot.	,,	1906
5 miles (standing start) . . .	2 $47\frac{1}{5}$	107·7	Marriott.	,,	1906
10 miles (standing start) . .	6 15	96·0	Macdonald.	,,	1906
15 miles (standing start) . .	10 0	90·0	Lancia.	,,	1906

DISTANCE RECORDS.

Time.	Distance.	Average Speed.	Holder.	Where made.	Year.
1 hour. . .	89 miles 892 yards.	89·5	Smith.	Brooklands.	1909
2 hours . .	173 miles 810 yards.	86·7	Smith.	,,	1909
12 hours . .	799 miles 1,600 yards.	66·7	Edge.	,,	1907
24 hours . .	1,581 miles 1,310 yards.	65·9	Edge.	,,	1907

[NOTE.—*The thanks of the writer are due to Messrs. De Dion Bouton, Ltd., for permission to reproduce the illustration of the De Dion Tractor; also to the Mercedes Company, Messrs. A. Darracq and Company, and Messrs. S. F. Edge (1907), Ltd., for the loan of photographs of Mercedes, Darracq, Napier, and Hutton racing cars.*]

INSERTING A 25-LB. BOMB IN A 200-FEET BORE-HOLE.

ARTESIAN WELLS, AND HOW THEY ARE BORED.

BY WILLIAM H. BOOTH, M.Am.Soc.C.E.

FROM time immemorial value has always been placed upon wells. So highly are wells esteemed that even amongst the most barbarous races they are rarely poisoned in the path of an advancing enemy. In torrid climes good water is often unobtainable on the surface. The well, however, dug deeply down into the ground, reaches water which has percolated perhaps many miles horizontally along the strata of the earth from regions, such as hills, that are more favoured with rainfall than are the arid plains.

Artesian Wells.

All ancient wells known to European civilization were formed by digging circular shafts into the earth, and, where necessary, lining them with stone or with bricks, or even with timber. In this country still exist dug wells which are believed to be of Roman construction. The artesian well, which now so often takes the place of the older dug well, is made by boring into the earth a comparatively small hole. This type of well had its origin, so far as we know as regards Europe, in the French

province of Artois; though later knowledge tells us that the bored well has been known to the Chinese for many centuries, so that the wells of Artois were at most but bored on a re-discovered method long familiar to the Chinese.

In a district where the water in the ground naturally rises above the surface when set free by a bore-hole, the artesian well with a diameter of only three or four inches is practicable.

Though the artesian well was primarily bored only where water was confidently anticipated to overflow the surface, the original signification of the term is now almost lost, and any well, bored, in place of being dug, is now quite commonly called artesian. Necessarily, such a bored well must be large enough to contain a single barrel pump of a size sufficient to raise the quantity of water required.

Every drop of water that exists in the ground comes originally from the atmosphere. A very usual estimate of what happens to the rain which falls upon the earth's surface is that one-third of it runs off promptly into the streams and rivers; one-third is dried up by the sun and air; and one-third sinks into the ground and subsequently appears as springs, or finds its way into the sea below water-level. It is obvious that all the fissures and porous rocks of the earth's surface, where accessible to rainfall, must be filled with water at least to sea-level, for the ground cannot possibly be drained by gravitation to a level lower than that of the sea. Over great parts of the earth's surface the ground is filled to much higher levels, and springs are found issuing from the ground even near mountain tops. The formation of a spring is simple. Rain sinking into the earth descends until it encounters an impermeable stratum. The water thus checked in its downward path flows along this stratum until it reaches the surface, and finds its way out through some opening.

Rainfall.

Where rocks are soluble, as are chalk and limestone, large underground water passages often exist, and rivers disappear entirely below ground in many cases where the rocks in which they flow are drained at some lower point. The Mole in Surrey is an example of a river which thus burrows beneath the surface; and the streams of the Derbyshire limestone may often be heard tinkling below their dry mossy beds in summer time, when the rocks are not filled to their customary winter's level.

Subterranean Streams.

It has occasionally happened that hard and much-fissured rocks have yielded water from wells, and living creatures have been found in it. But, as a rule, the water which penetrates to any depth below the surface must pass through a considerable thickness of surface soil. This thoroughly filters out all living germs, so that, as a rule, water from wells is of the highest organic purity. It contains only soluble minerals, such as carbonate or sulphate of lime, the two principal agents which render water hard. But otherwise the water contains nothing unsafe. Now, when a well is of large size, as it must be when dug, its water may be seriously endangered by the entrance of foreign bodies. Surface drainage soaks down behind the brick lining, and is often an unsuspected cause of danger; and in many ways the direct communication with the surface is a danger. Dug wells are always prone to run dry. They cannot be carried below water-level except by the assistance of powerful pumps. When a well is dug at a period of high-water level, it invariably runs dry sooner or later, and the writer has walked on the dry bottom of many a well and heading in the chalk. Then is the time to deepen the well to the low-water level, for years may elapse before a drought occurs so severe as to cause this deeper well to run dry. The water-level is always rising or falling, and

Dug Wells.

there is no real permanence of supply in a well dug barely below this zone. What is needed is evidently some method of making wells which shall reach far enough below the lowest drought water-level, and shall be safe from any of the dangers of pollution enumerated above.

SINKING A WELL IN A RIVER BED.

(Photo, by courtesy of Messrs. Duke and Ockenden.)

The wells of Artois, which were bored into the earth by means of chisels and augers, have furnished the solution, though it is only by modern methods and materials that the full safety of the artesian method has been secured. The earlier bored wells were lined in a very inferior manner. Simple tubes of riveted sheet-iron were employed to prevent the earth from being pushed inwards. These crude pipes were inserted in the bore-hole and driven down with wooden mallets. Fresh lengths were riveted to the top of the pipe and forced down until no further progress could be made. Then a similar pipe of less diameter was inserted within the outer pipe, and this in turn was sunk into the boring as this proceeded below the lower end of the lining tube; and similarly other pipes of successively decreasing diameter, until finally the work was stopped by the finding of water, or the hole became too small to continue.

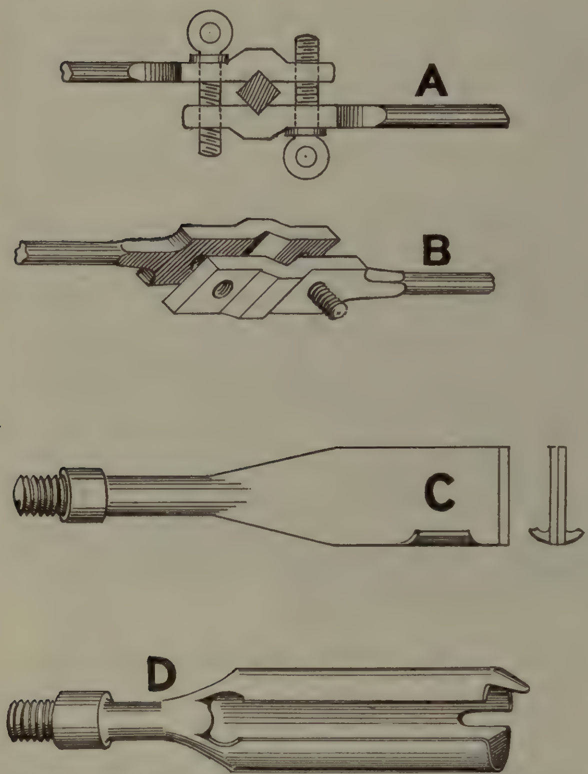
Lining Artesian Wells.

Practice and local knowledge determine the initial diameter which should enable water to be reached. A modern lining tube is never less than $\frac{1}{4}''$ thick, increasing to $\frac{5}{16}''$, or even $\frac{3}{8}''$ for larger sizes. The pipes are of lap-welded wrought-iron or steel, and are turned off squarely at each end to an exact length, usually of ten feet. A screw thread is cut on each end, after it has been "cressed" in, or reduced in diameter, by $\frac{1}{8}$ inch. Then upon the ends are screwed thin sockets of steel. As a result of the "cressing," the outer diameter of the sockets is only slightly larger than the body of the pipes. When tightly screwed up, the pipe ends butt closely together exactly at the middle of the socket. Pipes thus jointed will bear driving down into the earth by a heavy ram or monkey. The lower end of the bottom pipe is shod with a cutting edge of steel, and the top length of pipe is protected, during the operation of driving, by a heavy cap.

When a well is commenced, it is very usual to begin by digging a pit several feet deep. This is covered in with a stout platform, and through a hole in this the boring tools are worked.

Boring Tools.

Should the first stratum be clay, as it usually is in London, the tool employed resembles a huge carpenter's "nose bit," a sort of open-sided quill of sheet metal about 30″ or 40″ in length. On the upper end is screwed the first of a succession of rods from 1″ to 2″ square with threaded ends. These rods are



SOME OF THE TOOLS USED IN WELL SINKING.
A and **B**, rod tiller for rotating boring tools; **C**, a T-chisel for piercing rock; **D**, a clay chise .

made in lengths of ten feet, and are turned by means of long "tillers," or handles, clamped upon the square part. As the auger fills with clay it must be withdrawn—a tedious process, involving the unscrewing of the rods one by one.

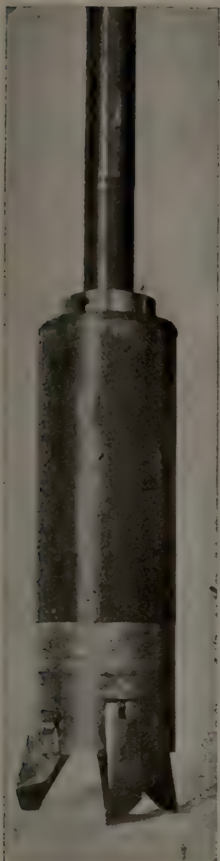
When rock is met with, the auger is replaced by a chisel of flat or of T shape, and the operation of chiselling is carried on by wrapping the winding rope round the winch barrel a couple of turns. The loose end is hauled by hand, causing the rope to grip the rotating barrel, and the rods and chisel are lifted a few inches. Then the rope end is released suddenly, and the chisel falls on the rock and cuts it. The rods are rotated slightly between every two strokes, so that the chisel may not fall twice in the same place. The side of the chisel trims the hole truly circular. (Sometimes a circular chisel is used, to cut cylindrical cores of rock. In American practice the tools are made very much heavier and the derricks are much more lofty than is usual in England, and the rods are lifted and dropped by means of an oscillating beam worked by an engine, as described in a previous article dealing with petroleum wells (vol. ii., p. 321 foll.). Sometimes in place of rods, which take so long to draw up, a rope is used, and a heavy string of tools is attached to it. The rope can be wound up rapidly by the winch. The string of tools must be long, so as to bore a straight and truly vertical hole; for if a hole goes very crooked, progress will be slower and the tendency may be, and sometimes is, to increase the crookedness and stop progress.

The Diamond Drill.

A great invention was the method of boring with diamonds. In this system the boring rods are of iron pipe, and the boring bit is a short cylinder, about $\frac{3}{8}''$ to $\frac{1}{2}''$ thick, having a few diamonds set round its lower end. The best stones for the purpose are Brazilian carbonadoes, or black diamonds. The holes in which they are set are drilled into the edges and end of the crown, and cut by chisel to fit the stones, which are made fast by burring over the soft iron of the crown. Boring is effected by rotating the crown rapidly upon the rock, a copious stream of water pumped down the hollow rods washing up to the surface the débris through the annular space between rods and rock. Diamond crowns bore their way several feet per day into rocks so hard that the ordinary chisel cannot advance six inches in the same time.

The Calyx Drill.

Diamonds were first used by a man named Leschot, who was able to buy them for about twelve shillings per carat. But after the introduction of the diamond drill the previously almost worthless black diamonds rose steadily in price until, ten years ago, they reached the high figure of £7 per carat, and diamond drilling became too costly Out



A CALYX DRILL.

of the general struggle to find a substitute have emerged two successes—the calyx drill and the shot drill. In the calyx drill a crown of steel with large saw-like teeth is rotated upon the rock. It resists the turning effort, applied at the top of the rods, for part of a turn; then it slips suddenly under the torsion strain of the rods. This rapid jumping action is very effective in cutting the rock, and gives good cores. The calyx drill cannot, however, penetrate really hard rock. For this work the shot drill proved its superior fitness The shot boring head is a cylinder of steel slotted upwards in the end at several points. Small chilled steel shot, poured down the hollow rods with the water, get in below the end of the boring

Shot Drilling.

crown by way of the slots and are rolled between the steel head and the rock. The curious rolling action breaks up the rock, and the débris is washed up. Progress is as rapid as with the diamond, and the cost of the chilled shot is only a small fraction of that of a single diamond.

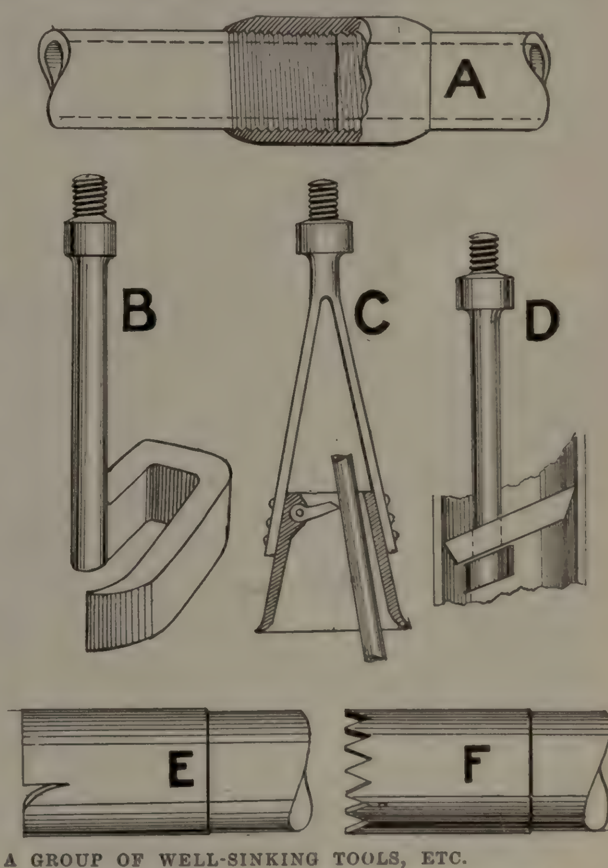
That such work can be done by small chilled shot may seem curious, but is explicable by a sort of mathematical reasoning. In mathe-

Its Principle.

matics a point hath no magnitude. When a perfectly hard sphere rests upon a perfectly hard plane surface the two bodies make contact at a mathematical point. Now, since a point has no area, the pressure at the point of contact must be infinite. Even the weight of a little chilled shot $\frac{1}{16}''$ diameter is something, and since the shot rests on a point of no area, the pressure must be infinite. In shot drilling we do not get mathematical points of contact, nor infinitely hard surfaces, but we are able to place a heavy pressure on the small shot which roll between the end of the crown and the rock. This pressure is far beyond what the rock can withstand, and so the latter is crushed by the shot and the particles detached and washed away The next little shot rolls over the clean path and crushes the surface again; and so the work goes rapidly forward. The removal of the

Detaching Cores.

core is effected by pouring some grit down the tubes to wedge the core against the walls of the tube, and



A GROUP OF WELL-SINKING TOOLS, ETC.

A, butt-jointed pipes, with tapered collar; B, a "crow's-foot;" C and D, latch tools for getting hold of broken rods and pipes; E, a shot drill, showing slot by which the steel shot gets under the bottom of the drill; F, circular chisel for rock work.

hauling upwards with the steam winch. In some cases the core is so stubborn that hydraulic jacks have to be requisitioned to break it away from the mother rock. A core 15 inches or so in diameter, 8 to 10 feet long, and weighing a ton and upwards, necessarily offers considerable resistance by reason of its great weight, apart from this adhesive force.

A string of rods and tools some hundreds of feet in length may be made of the very best materials, but so severe are the shocks to which it is subjected that it is small wonder that breakages sometimes occur. It is, however, a comparatively simple matter to rescue a broken rod from a depth of some hundreds of feet.

ARTESIAN BORED TUBE WELL AT BOURNE, LINCOLNSHIRE. INTERNAL DIAMETER, 13 INCHES; DEPTH, 134 FEET.

The water is seen issuing from the well at the rate of 3,480 gallons a minute, or 5,011,200 gallons per day. This is one of the most productive wells ever bored.

(Photo, by courtesy of Messrs. C. Isler and Co.)

Retrieving Broken Tools.

The other rods are let down with a "crow's foot" attached to the end. A "crow's foot" is a tool which will pass down a bore hole of a given size when this is occupied by a rod. It is first tried in a pipe of

the size of the lining tube to see if it is of a suitable size, and is then lowered down the bore-hole beyond the upstanding end of the broken rod and past the first joint. A rotation of the crow's foot causes it to grip the broken rod, which is then hauled up. Sometimes the operation is not so straightforward, for the tools at the lower end of the broken rods may become set fast by grit settling round them. Circular tools and shell pumps are very liable to be stuck fast by such gritty sediment, and it is an axiom with well-borers never to leave a tool at rest at the bottom of a hole, but always to draw it up fifteen or twenty feet so as to be out of the region of sediment. Powerful hydraulic jacks often fail to extract such "stick-fasts." Sometimes the rods are pulled apart by the stress, and breakdowns, perhaps three deep, are piled one above another in a narrow bore-hole. As a last resource for dealing with a hopeless stick-fast, dynamite, or some other explosive, is used. A charge

Explosives.

of a few pounds of high explosive detonated at the bottom of a bore-hole will sometimes blow all obstructions into the sides of the hole, and allow the lining pipe to be forced down past the spot. Explosives are often employed also to make a bore-hole yield a better supply. It may happen that the hole has traversed no fissure, and yields but little water. A "shot" may fracture the rock through to some fissure, and make a passage by which water can reach the boring. Such shots are by no means always successful.

A "DANDO" SAND SCREEN BELT.

This is a brass cylinder with vertical V slots cut from the inside. The point of the V just comes through the outside wall, forming a mere slit. Water has the property of flowing freely through a slit so narrow as to exclude even fine sand.

WATER GUSHING FROM A WELL AT SLOUGH JUST AFTER STRIKING THE GREENSAND.

The output is 100,000 gallons per hour. The large horizontal bevel wheel in the centre is driven by steam to revolve the tools.

(Photo, by courtesy of Messrs. C. Isler and Co.)

A DRILLING RIG AT WORK.
One of the men is seen turning the rods by means of a tiller.

Other salvage operations that the well-sinker must be prepared to undertake are the unscrewing of rods while in the bore, the recovery of the pipes, and the cutting off of pipes below ground.

For the first of these he uses a tool with a bell-shaped end, in the inside of which is chased a left-handed screw thread. This tool is attached to rods—which also have left-handed screw joints—lowered to embrace the top of the uppermost rod, and rotated in an anti-clockwise direction. The bell works its way on to the rod, and when the resistance has increased to a certain point the rod unscrews from that next to it, or some other joint lower down gives, and the released rods can be drawn up. The operation is repeated until all the rods have been retrieved.

Instead of a bell a "latch box," with spring catches which take hold of a joint, may be used. The same tool also serves, in some cases, for rescuing pipes. An alternative is a somewhat similar instrument which grips the pipe on the inside. It sometimes happens that the well-sinker is in doubt as to what kind of an end there is to take hold of. He therefore lets down on the end of a rod a socket filled with stiff clay or putty, in which an impression of the obstruction is obtained to guide the devising of a special tool to deal with the case.

Rescuing Pipes.

To sever a pipe below ground requires the use of a pipe-cutter. This consists of a piece of piping with three or four slots cut in the circumference at right angles to the axis. Through each slot projects a sharp-edged disc of very hard steel, carried on a spring which can be forced outwards by means of a long tapered bar pushed down inside the pipe. The principle is the same as that of the ordinary pipe expander. The discs are gradually forced outwards by the tapered bar as the tool revolves, and eat their way into the pipe until the latter has been completely severed, and can be raised by a latch tool.

Cutting Pipes below ground.

Occasionally a drill crown is cut through by the fragments of some hard substance which fall into the bore. As an instance of such an occurrence, we may quote what happened in a well being sunk by Messrs. C. Isler and Co. At a depth of 848 feet sharp flints dropped out of the chalk through which they were boring, and cut away the crown as cleanly as if it had been turned off in a lathe. The detached crown was nearly 18″ in diameter, and $\frac{7}{8}$″ thick. When the obstruction had been removed—this operation gave a great deal of trouble—boring was resumed. The same mishap was repeated three times, and in one case a string of tools over 20 feet long was severed by the flints, which were finally checkmated by means of a temporary lining driven down to keep them in their natural positions.

On the tools so far enumerated all others are more or less modelled. On the Continent, coal-pit shafts of 18 feet inside diameter are bored through water-bearing strata by means of huge combination chisels and tools resembling those used for well-sinking, but, of course, very much larger. The lining of these shafts consists of rings of cast-iron tubbing lowered from the surface, ring after ring being bolted to the upper end of the topmost tier. In this way water-bearing rocks are cut through without the aid of pumps, and when dry rock is reached the lower cutting edge may be sunk into it, or a water-tight joint may be made on hard rock by means of a "moss box," a contrivance whereby a quantity of moss is compressed upon the rock by the weight of the cylinders. The further progress of the shaft through the dry strata now reached is effected by the ordinary methods.

DIVER ABOUT TO DESCEND A WELL TO ADJUST A VALVE BELOW WATER.

In America an artesian basin of considerable depth occupies a good part of the State of Dakota. The water-bearing rock is a sandstone of which the surface outcrop lies along the foot-hills of the Rocky Mountains and around the Black Hills. The melting snows, no doubt, furnish much of the water which rises with so much force in the numerous bored wells that have been sunk in the Dakota basin.

American Wells.

The earliest discovery was made in 1881 in the James River valley by the Chicago, Milwaukee, and St. Paul Railroad Company. They sunk a six-inch well to a depth of 920 feet, and it flowed at the rate of 830 gallons per minute. To-day there are hundreds of artesian wells in the area of the basin, which measures 400 miles north and south, and 150 miles east and west. The wells serve variously for town supply and for irrigation, but many are made to produce power. One of the chief of these power producers is situated at Woonsocket. It is 775 feet deep and only 7 inches in diameter, yet it yields over 4,000 gallons a minute. When its closing valve is shut, the static pressure of the water is 165 pounds to the square inch. This drops to 62 pounds with a 4-inch outlet and 75 pounds with a 3-inch outlet. It drives a roller flour mill by means of a 3-foot Pelton wheel running at 275 revolutions per minute with a single 1¾-inch jet, and saves £1,200 per annum as compared with equal steam power.

Another well at Springfield is 593 feet deep, with an 8-inch lining tube and a pressure of 130 pounds per square inch. This drives a flour mill by means of a 16-foot turbine rotating 800 times per minute, and grinds eighty barrels of flour per day.

At Chamberlain, where the sandstone was loose, and possibly the casing was put in somewhat carelessly, water began to leak up

outside the 8-inch casing pipe, and defied all efforts to check it. Ultimately the heavy rush of water completely ruined the well, which had finally to be abandoned as unmanageable, being left to flow as a permanent spring.

Overflowing wells will always occur when a water-bearing rock receives rain or snow at a considerable elevation, and dips thence below some impermeable stratum up through which the water cannot escape as a natural spring. When such an artesian basin is tapped by many wells, these much diminish the stream flow from the outcrop or other point of drainage. Ultimately an increase in the number of the wells reduces the head of water in the rock, and diminishes the flow. London, a comparatively small basin of limited outcrop areas, is a striking example of this process. Not a single well now overflows to the north of the Thames within several miles of the river, so great has been the pumping draught of the many wells over the Metropolitan area; and the once overflowing wells south of the river have now all to be pumped.

Great as is the importance of a good water supply in a country blessed, as England is, with a good annual rainfall, it is doubly great in a region where, during part of the year, rivers and streams dry up, and at the best only a few pools remain. In a previous article (vol. ii., p. 312 foll.) have been noticed the artesian wells of Australia, which are as remarkable for their depth as for their productiveness. The latter quality is due to the fact that they overflow naturally. The average yield is about 700,000 gallons a day. The deepest bore-hole in the country, that at Bimerah, goes down 5,046 feet, or nearly a mile.

Australian Wells.

Only those who have actually bored an artesian well in a thirsty land can appreciate the importance of the work, and the widespread interest aroused by it. Steadily the long line of tools eats its way down into the ground; slowly rises the débris detached. Five hundred feet are pierced, but still no sign of water. A thousand feet, and only dry rock. But the engineer does not lose heart, knowing that if only he perseveres the chances are heavily in his favour. A depth of 1,500 feet is at last reached. How much further will the hard dry shale continue? At last the experienced workman becomes conscious of a change. He *feels* that he is in another kind of rock. Water creeps sluggishly up the bore-hole, and dribbles over the protector flange of the lining tube—the first sign of success. The men, greatly encouraged, work on, and the water-flow gains strength. The dribble is replaced by a fountain, 2, 3, 4, 5, 6 inches high, darkened by the muddy débris. The advance becomes more and more rapid, and in due course an 8-inch jet rises 3 clear feet above the top of the tubing. Now for a test. A 500-gallon tank is filled in one minute. Multiply that quantity by 1,440,

PUMPING FROM AN ARTESIAN WELL.

and the total daily flow is ascertained—720,000 gallons—quite a nice little river, which will slake the thirst of thousands of sheep, cattle, and horses, and enable many stock owners to weather a severe drought; for the subterranean sources of supply are affected not at all by the lack of rain in the district which they supply. Until the engineer came along with his tools inexhaustible supplies flowed within a few hundred yards of doomed flocks, to escape perhaps to the ocean bed somewhere in the Great Bight. Now this bad state of things has been removed in great part by the steel tubes which connect the pent-up subterranean reservoirs with the upper world.

The Air Lift.

One of the principal defects of a bore-hole from which the water does not flow naturally is that the water supply to be obtained from it is limited, not by the diameter of the bore-hole, but by the capacity of the pump that can be put inside it. Thus a 6-inch hole, 170 feet deep, with its water supply coming all the way from the bottom of this length of bore, will deliver 500 gallons per minute under a head of 10 feet. That is to say, if the water would rise to 13 feet over the surface, and the lining pipe be cut off at 3 feet above the surface, it will yield the above amount. But inside a 6-inch pipe the largest practicable pump is only about 5 inches diameter, and its yield would not exceed 2,000 gallons per hour when worked comfortably. Unless a well can be pumped from the surface, its supply is thus much curtailed. But when the water-level is not too far below the surface in comparison with the total depth of the well, a very full yield can be obtained by means of compressed air. To carry this out, the rising main is inserted down the bore-hole to about three times the distance which the water-level stands below the surface, or is likely to stand when the pumping is in operation at a given rate previously fixed as the result of a pumping test.

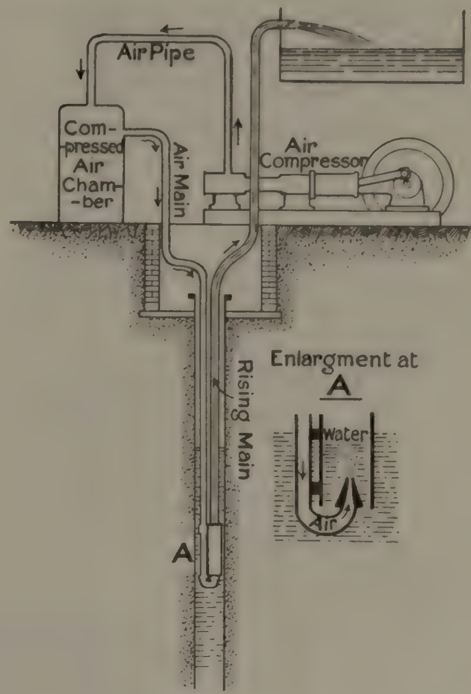


DIAGRAM TO SHOW THE PRINCIPLE OF THE "AIR LIFT" APPARATUS USED FOR RAISING WATER WHERE PUMPING IS IMPRACTICABLE.

(By permission of Messrs. C. Isler and Co.)

Sometimes the rising main stands inside a slightly larger air pipe, and sometimes the air supply pipe passes down inside the rising main, or it is carried down as a separate small pipe alongside of it. (See illustration.) The lower end of the air pipe opens by one or more openings into the foot of the rising main. When air is pumped down it escapes into the rising main, and converts the whole column of water into foam or into an alternation of water and plugs of air. The result is that there is less water in the rising main from its foot-piece to its surface outlet than there is between the surface of the water in the bore-hole and the foot of the rising main. Thus the external column exerts a greater pressure than the internal aerated column, and the result is that the water flows continuously into the foot of the main, is aerated, and rises to the point of discharge. Obviously, if the water-level is far below the surface, the total depth of the

bore-hole must be very considerable—greater than necessary merely to reach the water.

Disadvantages and Advantages.

One of the disadvantages of the air lift is that it involves excessive first cost under such circumstances. Then again, if much of the yield of water comes into the well above the level of the rising main, it must first find its way down the annular space between the rising main and the bore-hole well. This limits the outside diameter of the main to such a size as will not unduly restrict the downward passage of the water. A compromise must be made to suit such a case. To the credit of the air lift are the following facts: That it can be worked from a central point at any reasonable distance; that a great output can be got from a bore-hole if water be present in sufficient quantities; that there are no moving parts down in the bore-hole to get out of order; and that water carrying sand and other abrasive substances, which would make the use of an ordinary pump impossible, can be dealt with.

A PRODUCTIVE WELL (AUSTRALIA).

THE STATION AT HALLINGSKEID.

THE CONSTRUCTION OF THE BERGEN-KRISTIANIA RAILWAY.

BY R. H. UHLAND.

This railway, the greater part of which was but recently opened for traffic, is a marvel of engineering, as its construction was accompanied by climatic conditions such as railway builders seldom have to face. It is certainly one of the most wonderful of all European adhesion railways.

THIS year will be completed one of the most interesting railways in the world—that putting Bergen, Norway's greatest commercial centre, in direct land communication with Kristiania, the Norwegian capital. The railway is only 305 miles long, but the difficulties encountered in its construction make it as notable from an engineering point of view as the wildness of the country through which it passes will render it invaluable to the tourist in search of Norway's finest scenery.

The Route of the Railway.

The accompanying sketch map (p. 348) shows the route followed by this remarkable railway. From Kristiania northwards to Roa it uses the metals of the railway running to Gjövik. At Roa it turns south-westwards to Hönefoss, and thence north-westwards to Gulsvik near the head of Lake Kröderen. This

section is not yet completed; but already trains run between Gulsvik—which at present is reached from Kristiania by a rail journey *via* Drammen and Vikesund, and a steamboat trip along the lake—and Bergen. The central section—Gulsvik to Vossevangen, or Voss—opened in 1907, demands most attention, as it crosses the great water-shed of the Lang Mountains, passing through some of the wildest mountain tracts in Norway, far above the tree limit, in the region of eternal snow. As regards the greatest elevation attained—4,208 feet at Taugevand—the railway is surpassed in Europe by the Brenner Pass and Arlberg routes, and in America by several trans-continental railways. But it should be pointed out that even the Southern Pacific crossing in the Sierra Nevada, with its maximum elevation of about 8,200 feet, does not rise above the level at which firs, the hardiest of trees, cease to occur; whereas the Bergen railway, owing to its much more northerly latitude, leaves trees behind at an elevation of about 2,000 feet. The extreme severity of the winters, which cover the country with a thick blanket of fine hard snow, packed tightly into every hollow and crevice by violent gales, rendered the construction of the railway, especially at the higher altitudes, a very difficult task indeed. In the mountains snow falls even in June, and during a cold summer the snowdrifts and the ice covering the lakes do not melt at all. In laying the line, however, the engineers were careful to raise the road-bed, where possible, above the general level of the ground, so that the winds might assist in the task of keeping it free from snow. For 12½ miles the mountain section of the line has been covered in with snow-sheds, and 28 more miles are sheltered by snow-screens. The section is only 62 miles long, so that if the 9¼ miles of tunnel also be deducted, it becomes evident that only a very small proportion of this section is left entirely unprotected.

Elevation compared with that of other Railways.

Early History.

As long ago as 1870 a scheme was put forward for running a railway across the "Great Mountain." At that time the sea afforded the only means of communication between Bergen and Kristiania. Not even the roughest of roads

MAP OF THE BERGEN-KRISTIANIA RAILWAY.

The section between Gulsvik and Roa will be opened this year.

crossed the plateau; in fact, the high ground was practically an unexplored region, inhabited during a few months of the year by but a few herdsmen. As a first instalment, the Storthing voted, in 1875, the necessary money for building a narrow-gauge railway from Bergen to Vossevangan; and this line, which required some clever if not difficult engineering, was opened for traffic in 1883. While it was building, a survey of the mountains beyond and observations of the snowfall were begun, in anticipation of the time when an extension eastwards of Voss should be demanded. In 1876 the preliminary survey was completed, and next year appeared a first estimate of the cost. During the six years 1884–89 regular snow measurements were taken by peasants acquainted with the mountain districts. To assist them the State engineers erected at suitable intervals, on masonry bases, long poles, all duly numbered, from which the depth of the snowfall could be ascertained.

THE BERGEN RAILWAY BETWEEN OPSET AND VOSS.
A SUMMER VIEW.

After nineteen years of surveying and deliberation, the route was more or less definitely fixed to pass from Voss up the Raun Valley to the Urhovde mountain, through which a tunnel would be driven to Myrdal on the eastern side—on to the "divide" at Taugevand Lake, and thence through the Finse Valley past the Uste Lake to low ground at Gulsvik, which point would act as a temporary terminus while the last section to Roa was being completed.

A grant for the Voss-Taugevand section was made in 1894, and in the following year began the setting out of the line, which included the fixing of the axis of the great Gravehals or Urhovde tunnel, 5,800 yards in length, by far the longest of the 178 tunnels which occur on the Bergen-Kristiania railway. This work occupied six years, being greatly hindered by the intense cold and the exceedingly difficult character of the country, which made it necessary in places for the surveyors to be suspended by ropes over the edge of precipices while making their observations.

The Mountain Section surveyed.

As the Gravehals tunnel would have to be pierced from both ends simultaneously, and the mountain interposed an obstacle over which a transport road could not be carried, the engineers constructed a road up from Voss to Opset at the western portal, and

A ROTARY AT WORK, PUSHED BY THREE LOCOMOTIVES.
A SNOW-PLOUGH ABOUT TO ENTER A SNOW-SHED.

another southwards from the Sogne Fjord up the Flaam Valley to Myrdal at the eastern end. This latter road was eventually continued right along the line of the railway to Gulsvik, to supply the construction gangs with provisions and materials. The making of these roads as a preliminary to the actual building of the track was a somewhat arduous business, but one which could not be shirked, as on the roads, until the Gravehals tunnel should have been pierced, the men on the mountain sections east of Myrdal were entirely dependent. Simultaneously with the roads, telegraph and telephone lines were carried up-country; and barracks were built for the workmen out of materials transported over the heaviest gradients by means of cableways.

Building Transport Roads.

ENTRANCE TO A TUNNEL NEAR MYRDAL.

The short snow-shed seen is to prevent the entrance being blocked by snow-slides. In the foreground is a snow-fence.

The principle adopted was to work hard on the roads during the short summer, and to erect barracks and furnish them with stores at points where tunnelling had to be done, as this work could be continued through the winter after the roads had become snow-blocked and nothing more could be done in the open. While one section of road was in course of construction, the surveyors were marking out the section next ahead. In 1901 road building was started on the Hallingsdal or eastern side of the mountains, and also on the lower lying ground towards Gulsvik By September 1902 a cart could be driven from the head of the Sogne Fjord to Ustevand. As soon as a barrack was finished it was filled with labourers. Eventually, at great expense, and after overcoming many difficulties, the engineers completed the roadway and electrical means of communication.

The Roads completed.

The transport roads finished, materials were brought up in bulk, and it became possible to construct some of the permanent station buildings to serve temporarily as homes for the staff. Each station had its storehouse and bakehouse, the first well stocked during the summer with clothes, tools, tinned goods of all kinds, flour, and potatoes. To avoid the need for laying in large quantities of wood against the winter to run the bakehouses, the bread was baked in large batches as soon as the cold weather set in, and

SNOW PROTECTION AGAINST VERTICAL SNOW FALL.

kept in good condition by being allowed to freeze.

For two periods of the year the working parties were entirely cut off from outside—while the snow fell most thickly, in November and December, and while it thawed in the early summer. During the winter proper it was possible to get a limited quantity of goods up from the sea on pack horses, which, following one behind another, trampled a narrow, hard track in the snow.

Climatic Obstacles.

Open-air work was continued as far into the autumn as the weather permitted. Then the majority of the navvies sought the low-lying districts, where work was still possible. Only sufficient remained behind to continue the tunnel work, which in the longer tunnels never ceased day or night until completion. As débris could not be removed beyond a tunnel's mouth while the snow was still falling outside, the tunnel itself had to serve as dumping ground until after the thaw had begun. Consequently the force of men was so proportioned that the amount of material which they would be able to excavate should not unduly block the tunnel. In one of the longer bores the accumulations of a winter's work would amount to several thousand cubic yards. When the time arrived for moving the débris the men proceeded to dig a tunnel through the snow. Sometimes this tunnel would have to be considerably over a quarter of a mile long, and its construction, even with continuous work, would occupy two or three weeks. So tightly was the snow packed in the drifts that dynamite

Winter Work in the Tunnels.

A PEEP INTO A SNOW PROTECTION.

had to be used to shift it, the snow coming away in hard blocks just as if it were so much rock.

When at last the way was open, the men had to dig paths to the dumping grounds and clear them of snow—if the material was required for the formation of embankments—as snow covered with earth or stone would thaw so slowly that one summer's heat would not remove it.

In April and May some of the summer gangs were engaged. Their first duty was to clear the approaches to the many long cuttings in the rock, so that work might be begun upon them at the earliest possible moment. Had the engineers waited for the natural removal of the snow by thaw, the mountain section would have occupied several more years than it did. This shovelling work was at times very irksome and apparently useless, for over and over again a fall would refill a partly cleared cutting. Where the drifts were exceptionally deep—in some cases they measured 60 feet vertically—tunnels were driven through them to the working faces.

Clearing Snow from Cuttings.

By midsummer's day, or a little later, the transport road became practicable for wheeled traffic, and the materials collected in advance on the Sogne Fjord were brought up. By the end of July the working parties were at full strength, two thousand men all told being housed in the barracks. Only the hardiest men would engage for the mountain sections, as the climate, even in the summer, could be far from genial, and there were few recreations with which to vary the monotony of labour. Also, the

High Wages.

NEAR KLEIVA LAKE, EAST OF MYRDAL.
PASSAGE CLEARED THROUGH A 9-FOOT DRIFT NEAR TAUGEVAND.

men were not allowed to bring their families into the mountains. But by way of compensation the wages were high; and as few opportunities of spending money occurred, those men who kept to the mountain work for several years were able to amass a very considerable sum.

The Gravehals Tunnel.

The Gravehals tunnel is notable not only on account of its great length—17,421 feet—but because its construction was attended by the great difficulties caused by the great distance from a base of supplies, and by the fact that the workmen were entirely isolated during several months of the year. In fact, this may be considered one of the most arduous pieces of tunnelling ever accomplished, and worthy to rank beside the far longer Alpine tunnels which formed the subject of a previous article.

Italian Miners imported.

Excavation was begun in 1895, after a water-power station had been erected at each end to drive the pneumatic and hydraulic drills used in the Myrdal and Opset headings respectively. As the contractors could not obtain a sufficiency of native workmen accustomed to machine drilling, they imported, in 1900, fifty Italian miners who were experienced in this kind of work. Unfortunately, the rock encountered was so much harder than that previously mined by the Italians that events proved one Norwegian to be worth two southerners So when the Norwegians had learned the technique of the drills thoroughly the foreigners were packed off home again.

Hard Times.

During the winter 1902–3 the tunnellers at the eastern end had a very bad time. For two and a half months all communication with the outside world was cut off. Stores gave out, and coal and wood had to be doled out in meagre rations. Things looked so bad that there was serious thought of abandoning the work for the season and beating a retreat. But luckily, before such a course became necessary, the headings met, and bread was brought through from Opset.

Snow Blockades.

On some of the stormiest days of this winter the wind velocity exceeded the maximum which the anemometer could record—90 miles an hour. One of the houses in which the men lived was completely covered up—all but the chimney—by the snow, and could be reached only through a snow tunnel of considerable length. This tunnel was often blocked during the night by a snowstorm. Consequently, when the night-shift came off duty they had to shout down the chimney, and obtain the assistance of those inside to dig a way through. In such circumstances it is not strange that the men should have found their work unattractive. Even when travel was possible it was not free from danger. The way could easily be lost at night or during a snowstorm. The telephone line, if struck, could be made to serve as a guide by throwing a piece of string over the wire and drawing it along to the next post, where it had to be released and flung over the succeeding span. On one occasion a paymaster and his guide were lost in a storm and frozen to death.

The Tunnel completed.

In spite of all obstacles the tunnel was completed, after twelve years of incessant labour, in 1906. The rock blasting consumed 495,000 lbs. of dynamite and 310 miles of fuse, and required the drilling of 350,000 holes, with an aggregate depth of 217 miles. A further million pounds of dynamite were expended on the other numerous tunnels and on the cuttings, from which about 2,400,000 cubic yards of rock and earth were removed.

The track is of standard gauge (4 feet 8½ inches) throughout, the original narrow gauge track between Voss and Bergen having been changed to standard during the years

1898–1904, in order to obviate transhipment at the former place. The rolling stock includes two rotary snow-ploughs (see vol. ii., pp. 240–245), built in Norway on the American model. They cost about £4,500 a-piece, and are fitted with engines of 1,000 horse-power to revolve the great shovel wheel. Two pusher locomotives are able to propel a plough through the deepest drift. Thanks to the efficiency of these wonderful devices, the line was worked regularly throughout the winter of 1897–98. The ploughs are assisted in their work by a system of screens arranged on either side of the track square to the direction of the prevailing winds. The snow accumulates behind the screens until a deep drift has been formed, and then the screens are moved a bit nearer the track. In this way the depth of the drifts over the rails is kept within such compass as the ploughs can deal with.

Snow-Ploughs.

The only satisfactory way of obtaining an adequate idea of the real nature of the engineering triumph won by the Norwegian engineers responsible for the construction of this wonderful line is to traverse the line itself in one of the extremely comfortable observation cars which are at the disposal of tourists. The views to be obtained from the carriage window when passing between the great mountains of Hallingskarvet and the glacier on Hardangerjokelen are such as probably cannot be equalled on any other railway in the world. In the course of a single summer day the traveller is able to enjoy the great contrasts afforded by the flat landscape of the eastern country, the wild solitudes and wide prospects of the mountains, and the perpendicular cliffs and deep fjords which he passes between Voss and the western terminus.

A Railway for Tourists.

A VIEW IN BERGEN.

The Construction and Laying of Submarine Cables.

BY CHARLES BRIGHT, F.R.S.(Edin.), M.I.E.E.

CONSTRUCTION.

The Conductor.

THE important part played by submarine telegraphs throughout the civilized world centres itself in the electrical conductor, the rest of the cable serving merely to render the conductor lastingly effective in its object at the bottom of the sea.

For the conduction of electricity, whether for telegraphic or other purposes, this all-important wire is composed of the purest possible copper. Where considerable distances

Fig. 1.—TYPES OF ELECTRICAL CONDUCTORS (ACTUAL SIZE).

have to be electrically spanned, a solid wire of the required dimensions is too rigid, so the conductor is made up from a number of comparatively small wires laid up into the form of a strand of the necessary total dimensions.* On the other hand, for connecting points over, say, 750 miles apart, the central wire is, as a rule, substantially larger than those surrounding it, with a view to increasing the conducting properties of the line.

This is necessary in order to meet speed requirements by compensating for the considerable length entailed, seeing that the rate at which electrical signals can be transmitted through a cable varies inversely with the square of the length, in addition to being dependent on the type of conductor and its insulating envelope. In the same way, for still greater lengths a conductor with strips of copper outside a large solid wire has recently been resorted to.

Stranding the several wires together is effected by a vertical rope-making machine. Motive power is transmitted to this machine

* The total diameter of a submarine cable conductor varies from about ·069 to ·204 of an inch, according to the length and working speed requirements.

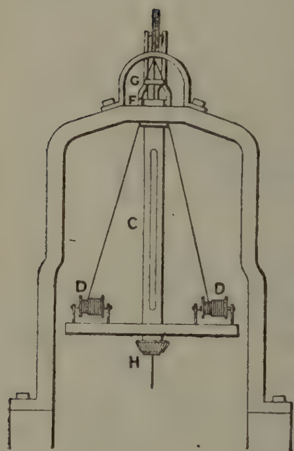


Fig. 2.—STRANDING MACHINE.

From C the wire is threaded through the die-plate G, where it is enveloped by the outer wires. The latter are worked on bobbins, D, mounted on a horizontal turn-table revolving with the shaft C. These wires are conveyed from their individual bobbins through the two dies F and G in turn, where they meet the centre wire, and are laid round it in more or less elongated spirals. The number of these bobbins obviously depends on the number of outer wires composing the strand. The so stranded wire is conveyed by means of a pulley to a measuring drum, and thence on to a carrying reel, which, when fully loaded, is taken off the machine and replaced by another.

from a steam or other available engine, the wire being stranded up in about 2-mile lengths, as a rule.*

The Dielectric.

Water being a good conductor of electricity, the copper wire has to be covered with some substance which is a bad conducting or insulating medium, to prevent much of the transmitted current leaking to earth, instead of going to the farther end of the line. Gutta-percha is found to be peculiarly well adapted to the purpose, its insulating qualities improving immensely under the pressure and low temperature of ocean depths.†

Gutta-percha is obtained from certain sapotaceous, wild-growing East Indian trees, from which it exudes when an incision is made in the bark. It arrives in this country in crude lumps, which are thereupon subjected to a series of cleansing processes before application round the conducting wire. A highly satisfactory machine, devised by the late Mr. Matthew Gray, for applying the purified gutta-percha, is depicted in Fig. 3.

With this apparatus several wires may be covered at once. They are hauled off their respective hanks through the die-box, containing dies in accordance with the thickness of the coating required, and thence through a long trough of intensely cold water so as to render the gutta-percha thoroughly hard before reaching the collecting drum. The exact thickness of this insulating cover is, like the conductor, governed by electrical considerations for obtaining the required speed of signalling through a given length.* It is also governed by mechanical considerations, a conductor of a certain size involving a thickness of insulation in proportion to that size in order to avoid buckling through due to great rigidity. This thickness may be anything from ·065 to ·139 of an inch, according to the length and required speed. The diameter of an ordinary insulated wire for submarine

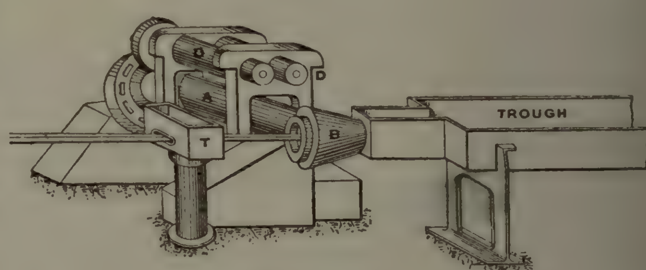


Fig. 3.—GUTTA-PERCHA COVERING MACHINE.

The gum, placed between the upper sides of the two rollers D D, is drawn down between them in a thin sheet, and forced along to a die-box, B, by the Archimedean screw A. The entire machine is steam-heated—so as to keep the gutta-percha in a plastic condition—and is driven by steam or other available power.

* Full particulars regarding this process may be found in "Submarine Telegraphs: Their History, Construction, and Working," by Charles Bright, F.R.S.E., A.M.Inst.C.E., M.I.Mech.E., M.I.E.E. London: Crosby Lockwood and Son.

† India-rubber (somewhat similar as a gum) is occasionally adopted for certain tropical waters invaded by the teredo and such other "objects of the deep" as have a *penchant* for the comparatively cheese-like gutta-percha.

* Full details in regard to this are given in the author's lecture to the Royal United Service Institution of April 17, 1907, as well as in "Submarine Telegraphs."

cables is very similar to that of a lead pencil, the wire conforming closely to the lead and the dielectric to the wooden case of the pencil.

It only remains to be said that the covering of the conductor with a suitable insulating dielectric is the most important feature in the manufacture of a submarine cable, besides representing the largest proportion of the total cost of the line. The conductor and dielec-

Fig. 4.—TYPICAL ATLANTIC CABLE CORE (ACTUAL SIZE).

This is made up of 650 lbs. copper and 400 lbs. gutta-percha per nautical mile.

tric combined are commonly termed "the core."

The core of a modern Atlantic cable provides for a speed of fifty words per minute by ordinary manual transmission, and, in effect, some 100 words a minute by the duplex-automatic system of sending signals in both directions simultaneously.

For teredo-ridden waters the core is protected by metal taping, applied helically. Inasmuch as no insulated conductor, such as we have described, could be picked up from any substantial depth for the purposes of subsequent repair, or even withstand the abrasion involved by some portions of the sea-bottom, the core is always covered with a sheathing of galvanized iron or steel wires, with a packing of jute between the core and the wires.

Mechanical Protection.

Inner Serving.

The jute yarns are served round the core by machinery of the same type as that employed for laying up the copper conductor strands, but set horizontally instead of vertically.

Armour.

The sheathing of iron or steel wires is applied in a similar helical fashion, by gear like that associated with the manufacture of ordinary wire-ropes. There may be anything from ten to twenty of these wires, and the diameter of each may be anything between 0·07 of an inch and 0·4 of an inch, according to the depth and nature of the bottom for which the cable is intended.

Galvanizing iron wires is an insufficient guard against rust in salt-water, and mainly on this account the sheathing is covered with a mixture of mineral pitch, tar, and silica—commonly known as Bright and Clark's Compound—which is again applied after the cable has been enveloped in an outer serving of hemp, the latter constituting a firm binding and further preservative. The silica in the compound serves as an additional protection against incursions by the teredo; and in modern practice each wire is either separately compounded in advance, or—for "main" types—enveloped in compounded cotton tape.

Cable Manufacture.

Fig. 5 below gives a general view of the simultaneous serv ng and sheathing of a cable. On the upper floor of the factory may be seen the drum of insulated conductor, with two jute serving machines for applying separate layers of yarn, each in opposite directions. From here the served core is drawn down, as

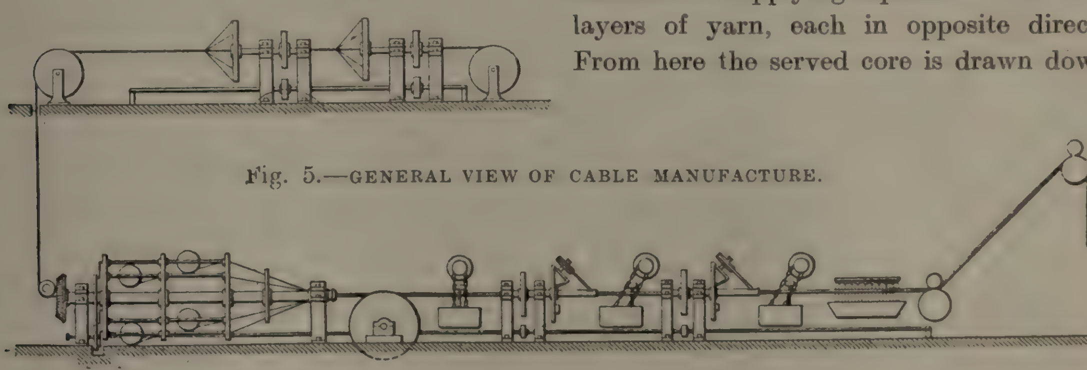


Fig. 5.—GENERAL VIEW OF CABLE MANUFACTURE.

shown, to the sheathing machine on the floor below, whence it is led through apparatus for applying the aforesaid compound—cold first, then a layer of canvas tape or hemp yarns, then hot compound, then another covering of hemp, or canvas tape with the reverse lay, then hot compound once more—the completed cable finally passing under streams of cold water to cool and harden the surface before being led to the storage-tank, where it is neatly coiled down,* after receiving a coating of whitewash to prevent the different turns and flakes of cable sticking together.

Jointing and Splicing.

The splicing together of different lengths of the cable is performed in the same way as in ordinary hempen or iron ropes. Space does not permit of this being described in the complete way that would be necessary to be of any real use. It is also impossible to describe here the important operations of making a joint in the insulated conductor, the secret of which is care, cleanliness, and experience. These operations have been fully recounted in the course of a paper contributed by the author to the Institution of Civil Engineers.†

Testing.

During every process of manufacture the line is kept under searching electrical tests, by instruments similar to those subsequently employed for signalling through the line, all of which have already been described in the chapter on "Early Atlantic Cables" (vol. ii., pp. 292, 295).

Rate of Manufacture.

The length of each constituent part of the line as made is measured throughout by revolution-counters fitted to each machine. About 35 miles is an average output of cable manufactured at a factory during an ordinary working day.

Types.

As already mentioned, the type of armour used in a cable varies considerably with the depth and nature of the bottom. For deep water, tensile strength and lightness being the main considerations, a small gauge-wire of mild (Bessemer) steel is therefore usually employed, such a wire giving a breaking strain up to 100 tons per square inch. For shore approaches, on the other hand, large metallic surfaces are required for withstanding abrasion by rocks, anchors, etc. Considerable weight is also necessary in these situations for contending with lateral strains due to strong currents. Thus here an ordinary class of iron wire ("Best-best" quality) is employed, but plenty of it.

A cable of the present day is constituted by at least three types—namely, "shore end," "intermediate," and "deep-sea" (or "main") cable.

The "shore end" is employed for some two miles from each terminus; the "intermediate"—a modified shore-end type as regards the class of wire used—to a depth of 200 fathoms, say; and the main cable for the remaining portion. Sometimes, however, as many as six different types are necessary for coping with the varying conditions along the route, a distinguishing letter or number being applied to each.

The "shore end" is, as a rule, furnished with two sheathings, the outer of which is composed of wires of quite large diameter, with bedding of jute between the inner and outer sheaths. The weight of such a cable is often as much as 30 tons to the mile.

In the case of the Irish shore end, illustrated in Fig. 6, the wires of the outer sheathing appear elliptical. In reality, however, they are the ordinary circular wires, but being applied with a very short lay, this appearance is produced in true section.

* This operation has already been depicted on page 286 of the chapter on "Early Atlantic Cables."

† "Inst.C.E. Minutes of Proceedings." Vol. clvii. See also the author's "Submarine Telegraphs."

Shore-end cables of this description are now largely used where local conditions demand sheathing which, besides being especially heavy, also offers a large metallic surface as a defence against trawlers, etc. The largest type of cable in existence weighs as much as 62½ tons per mile, being designed to resist the crushing strain of icebergs grounding on the coast of Newfoundland, where it was landed but a few months ago.

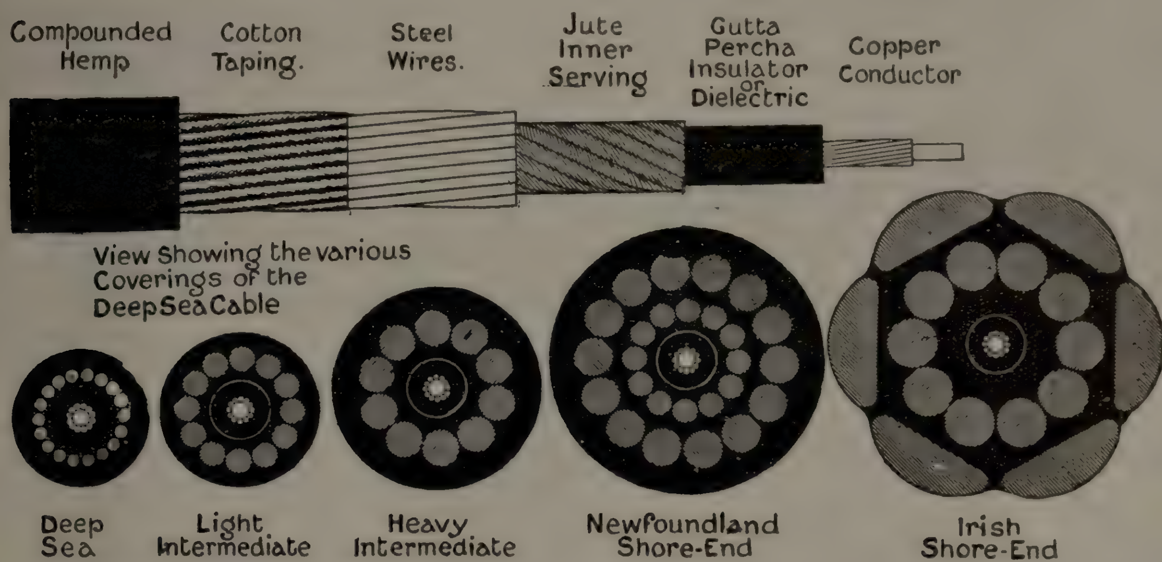


Fig. 6.—MODERN ATLANTIC CABLE TYPES ($\frac{4}{5}$ ACTUAL SIZE).

Deep-sea (main type) cable of the description depicted in the sectional elevation view is intended for maximum ocean depths of three or four miles. It will bear a strain of seven tons; and being, in consequence, capable of supporting a considerable length of itself, can be recovered and repaired in very deep water.

Though the general principles underlying all ocean telegraphy remain peculiarly the same as at first, steady advance has been made in the quality of the materials used in submarine cable manufacture. Indeed, the available strength of a modern deep-sea line, such as that represented by Fig. 6, is some 30 per cent. greater than was obtained in the earliest cables.

LAYING.

Preliminary Submarine Survey.

Strictly speaking, the manufacture of a submarine cable should not be embarked on until a survey of the route has been effected for determining the types to be adopted and the length of each. In any case such a survey is essential before the actual laying proceeds. In early days several disasters occurred owing to the lack of preliminary soundings, and the want of even a general knowledge of the bed on which the cable was destined to rest.

Some idea of what happens when a cable is laid over a sea bottom that has not been surveyed may be gathered from Fig. 7. In this example it may be observed that even if the cable did not break during the operation of laying, it would be pretty certain to do so soon after, due to the strain of being suspended from point to point. Such irregularities as are here depicted would require

very special precautions. They are, however, best avoided altogether, provided a more suitable route can be found.

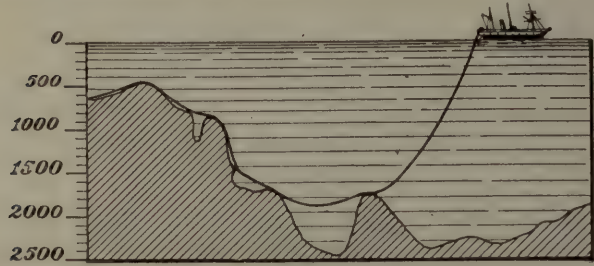


Fig. 7.—CABLE LAYING OVER AN IRREGULAR BOTTOM.

Fig. 8 represents the sort of bed that cables are laid on under normal conditions. Even then it is advisable to take soundings in ad-

Fig. 8.—CONTOURS OF THE SEA BOTTOM.

vance at intervals of about ten miles, lest there should be a submarine mountain—or, on the other hand, a valley—on the route, such as must be avoided, or allowed for, in laying.

All deep-water soundings are nowadays effected by means of very fine but intensely strong steel wire of the type employed in the treble notes of a piano, bearing a strain equivalent to 130 tons per square inch. With such a wire, and a suitable weight attached thereto, the depth is ascertained by noting the length which runs out before bottom is struck, the wire being afterwards recovered by means of a steam or other engine.* Besides measuring the depth, it is customary, by means of small metallic tubes † attached to the line, to secure a specimen of the bottom; and occasionally, with the aid of a suitable thermometer, to ascertain the temperature—also a matter of some importance—which at great depths is almost down to freezing point.

Telegraph Fleet.

Having dealt with the construction of a cable and the survey of the route preparatory to laying, we now come to the shipment of the line. There are, at the present time, no less than fifty-seven telegraph ships in active service in various parts of the world. Most of these, however, merely have to do with the maintenance of cables already laid; for there are less than a dozen large vessels employed for the original laying of ocean cables by the contractors, by far the largest of which are the Telegraph Construction and Maintenance Company's T.S. *Colonia*; the India-rubber, Gutta-percha, and Telegraph Works Company's T.S. *Silvertown*; and Messrs. Siemens Bros. and Co.'s T.S. *Faraday*.

The *Colonia* is the latest of the big telegraph ships, and has entirely outstripped all others of the present day in size and every other respect. With a length of 500 feet and a carrying capacity of 11,000 tons, she is capable of laying an entire Atlantic cable with the assistance of a smaller vessel for landing the shoal-water shore ends.

The *Silvertown* (p. 365) comes next in point of size. Her beam is as much as 56 feet, and she can carry 8,000 tons, though her length is comparatively inconsiderable.

* The apparatus and routine associated with deep-sea soundings has been fully described in Mr. H. D. Wilkinson's treatise on this subject, as well as by the present author in "Engineering" of January 13, January 27, and February 10 1899.

† On the principle of the Brooke sounder already described (vol. ii., p. 279) in the chapter on "Early Atlantic Cables."

Fig. 9.—TELEGRAPH SHIP "COLONIA."

Fig. 10.—TELEGRAPH SHIP "FARADAY."

Fig. 11.—H.M. TELEGRAPH SHIP "IRIS."

Fig. 12.—TELEGRAPH SHIP "TELCONIA."

The *Faraday* is a ship of very similar dimensions. This vessel is of interest in that, penny steamboat-like, she has bows (in addition to rudders) aft as well as forward, the idea being to facilitate cable operations.

Amongst smaller representative vessels we have H.M.T.S. *Iris*, the guardian of the All-British Pacific Cable, with a gross registered tonnage a little over a quarter that of the *Colonia*.

But though one of the smallest, the most interesting telegraph ship now is the *Telconia*, just recently built for the Telegraph Construction Company. She, in fact, forms the first cable-repairing vessel so designed that everything is ready to hand in its proper place, all the gear required for cable operations being forward, and the sailors' quarters relegated to the stern.*

Fig. 13.—TELEGRAPH SHIP "SILVERTOWN."

Cable and Machinery aboard Telegraph Ship.

Fig. 14 presents a general idea of the disposal of the line, as well as the machinery for handling it, on a vessel intended for telegraph work. This view happens to depict the *Great Eastern* with her historic cable cargo; but the same general plan is equally applicable to modern custom.

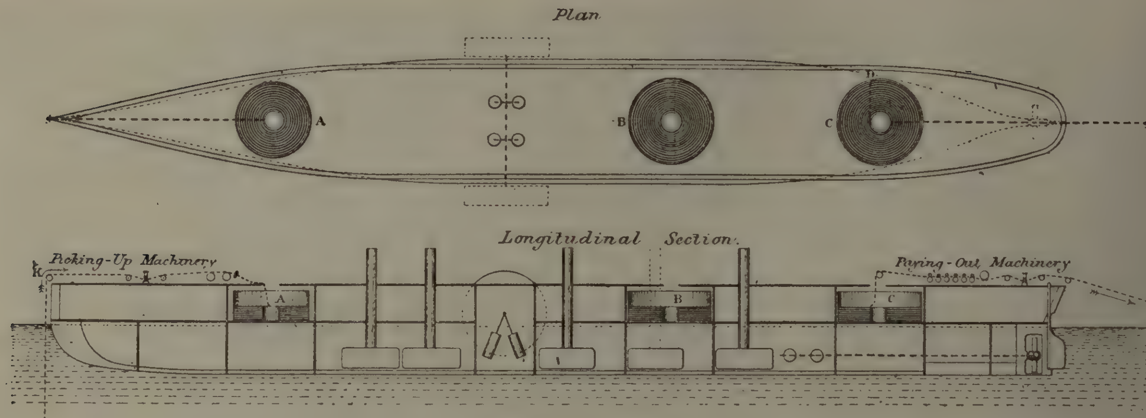
Shipment of Cable.

The line having been made at the factory, it is gradually stowed on board the ship, or ships, about to lay it on the route selected. The cable is drawn out from the factory tanks over tackle leading to the laying vessel,* into corresponding watertight iron tanks on board—of which there may be three or four for different types and sections of cable, apportioned in suitable positions ready for laying.

Fig. 15 illustrates one of these tanks, with the cable partially coiled therein—indeed, very closely packed in horizontal flakes, each carefully whitewashed to prevent sticking. Obviously no form of cable could be coiled to the very centre of the tank: the space is therefore usually filled up by a system of

* A full description of this craft appeared in "The Electrician" of July 16, 1909.

* As illustrated in the article on "Early Atlantic Cables," vol. ii. p. 289.



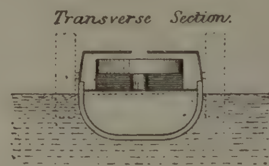


Fig. 14.—PLAN OF CABLE AND MACHINERY ABOARD S.S. "GREAT EASTERN." *

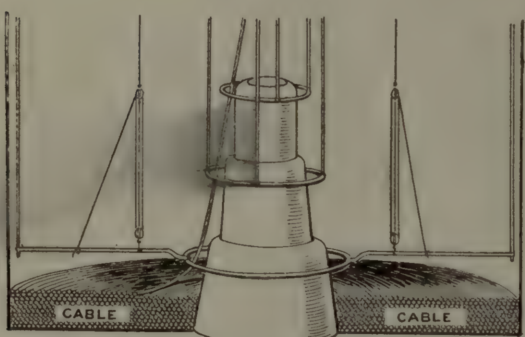


Fig. 15.—CABLE STOWAGE IN SHIP'S TANK.

hollow cones as shown. The tanks are also fitted, as may be seen, with some sort of outer iron framework, often termed a "crinoline." The two combined serve as a close and safe guide for the cable in its egress from the bottom of the tank at a more or less high speed when paying out. This framework (see Fig. 15) is supported from the top of the tank by tackle, which is lowered as required, in order, as the cable leaves the tank, to adjust the bottom ring to a height only about a foot above that of the upper flake of cable, and the other rings in similarly suitable positions relative to the top corners of the individual cones. By this means the egress of the cable is kept in close check throughout.

Having dealt with the installation of cable on board a telegraph ship, attention may now be turned to the apparatus and procedure for the various operations entailed, previous to dealing with the work of laying the wire.

Apparatus employed in Cable-Laying.

When paying out, the cable is (as may be seen in Fig. 16) drawn from the centre of the tank, through wooden or iron troughs, to a brake drum, by which a restraining force is applied to prevent too rapid egress outboard. The general principles of

Fig. 16.—GENERAL ARRANGEMENT OF PAYING-OUT GEAR ON BOARD THE "GREAT EASTERN."

* In the present article wherever an historical example is given, it applies equally to present-day practice.

this apparatus have already been described somewhat fully in the article on "Early Atlantic Cables." *

Fig. 17 shows a combined paying-out drum and brake of recent type, consisting of a large but light iron drum about six feet in diameter. Close against the rim of this drum, at the

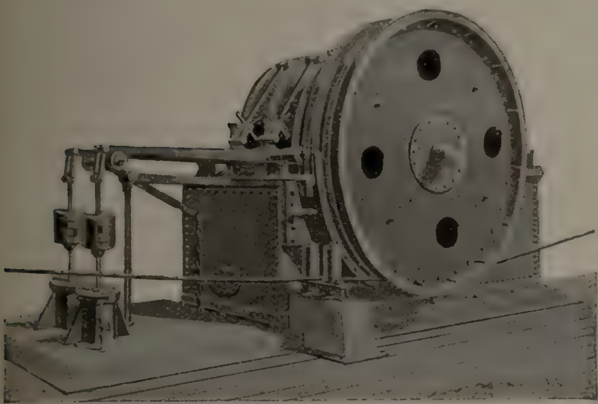


Fig. 17.—PAYING-OUT DRUM AND BRAKE.

point where the cable arrives at and quits the machine, are pieces of hard steel (see Fig. 18) fitting to its circumference. These are

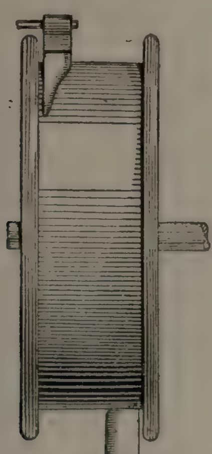


Fig. 18.—FLEETING KNIVES.

called "fleeting knives." As already mentioned in the earlier article, with a view to retaining a firm hold on the line whilst being paid out, this drum is made to take four or five turns of the cable, and the object of these knives is to prevent (by accurate guidance, or "fleeting") the incoming turn riding over the last turn, or off the drum. To the drum shaft is geared a revolution-counter, indicating the length of cable laid.

* Vol. ii., pp. 291, 292.

For the purposes of recovering on board a comparatively short length of line whilst in the act of laying—in the case of a fault or some untoward accident—it is usual for the paying-out machine to be fitted with steam gear. The same, also, is often required for paying out in a case where the cable outboard, in very shallow water, is not sufficiently heavy for it to run out freely of itself.

The general principles of the brake which forms part of this apparatus have, as already stated, been described (vol. ii., p. 292); and the same applies to the dynamometer gear, through which the cable passes on its way outboard from the brake to the ship's stern sheave.

By means of the dynamometer we obtain a ready indication of the amount of longitudinal strain to which the cable has been subjected. The stress on the cable can, indeed, be actually read off on a scale. The hand-wheel—shown in the previous article—for adjusting the brake-power is operated by a mechanic in accordance with the indicated strain. This winch controls a steel rope, the farther end of which is fastened on to the levers of the brake drum and weight platform.

Fig. 19 presents a good general idea of the paying-out apparatus on a modern telegraph ship, showing the mechanic at the dynamometer wheel (on the farther side), by means of which he is able, as stated in the previous article, to release all the weights on the brake levers at a moment's notice, as well as to reduce or increase the strain as required.

To meet any emergency such as might involve additional brake-power—especially if the drum apparatus failed—additional hold-

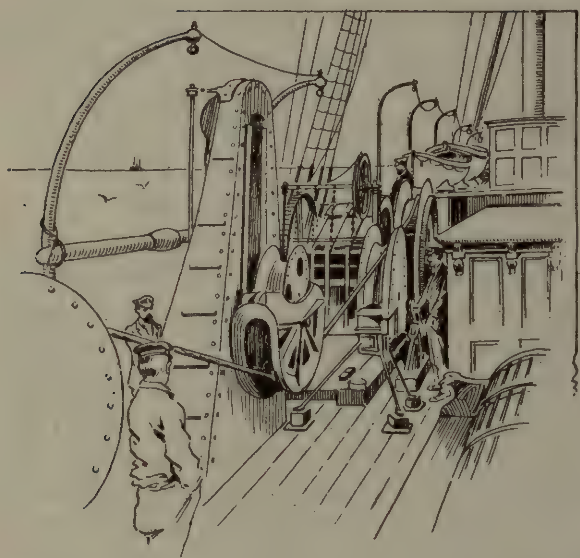


Fig. 19.—MODERN DYNAMOMETER GEAR.

ing-back machinery is usually provided on large vessels intended for cable-laying in deep water. This is placed between the cable tanks and the brake drum. It is sometimes constituted by several flanged wheels, each surrounded by a jockey pulley, thereby also providing a certain amount of tension before the cable reaches the drum.

Another and perhaps preferable form of auxiliary gear consists (as depicted in Fig. 20) of a double row of semicircular cast-iron pieces, placed on a solidly constructed table. One row is fixed, and the other row arranged so that each segment piece is opposite a vacant space in the fixed row. The former can be moved to and fro across the table by a system of bevelled wheels and threaded spindles. The interval between the rows may thus be increased or diminished at will, thereby providing for a varying degree of friction imparted to the cable and a corresponding variation in the speed of paying out.

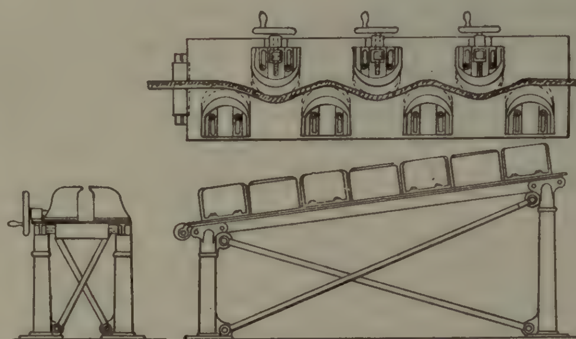


Fig. 20.—BRIGHT'S HOLDING-BACK GEAR.

This friction-table apparatus may be seen in position in Fig. 21. The same view also shows a double cylinder steam-engine fitted to the paying-out machine for the purposes already named.

In the forward part of a telegraph ship stronger gear (in duplicate for each bow) is fitted, similar to that which has been described aft, but more powerful. It is furnished with toothed wheels and brakes, which latter are controlled direct from the machine itself, the dynamometer apparatus in this case only serving the purpose of measuring the strain. The machine is actuated by a powerful two-cylinder horizontal engine, and has already been referred to and partly illustrated in the earlier article, with reference to the recovery of the second Atlantic cable. The entire picking-up apparatus is shown in the general view of the *Great Eastern* (Fig. 14), including the bow-baulks and sheaves over which a cable is picked up. Small repairing-ships only have, as a rule, forward gear, their

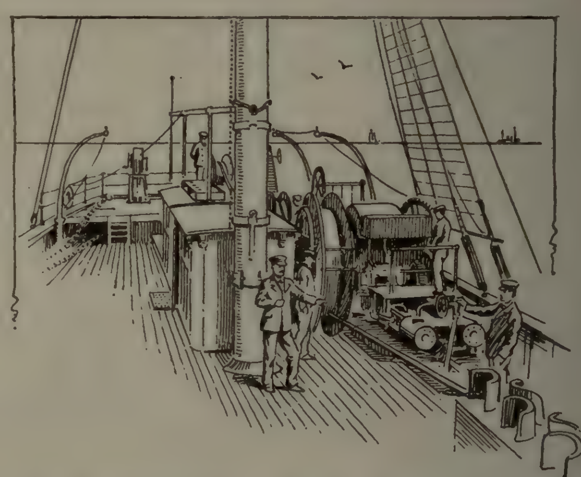


Fig. 21.—FRICTION TABLE ON T.S. "DACIA."

operations consisting mainly of grappling for and picking up cables, any short lengths subsequently laid being performed from the same machine.

The buoys used in cable work, together with their attachments, fixings, and moorings, are of various shapes, sizes, and descriptions, such as it would be impossible to deal with in detail here. Briefly it may be said that for shallow water, where the necessary moorings are no great weight, they need only be of small dimensions; while for great depths they are of considerable size, and capable of supporting three or four tons of moorings. The shape of a buoy is of great importance. A badly shaped buoy in a heavy sea will be so unsteady that it will soon chafe its moorings, and may even give such violent jerks as to break the flagstaff and lamp supports surmounting it. A very ordinary type of buoy for deep-sea cable operations is that shown on p. 369 of the article on "Early Atlantic Cables," and also—in operation at sea—as a heading to the said article (vol. ii., p. 277).

Cable Buoys and Cable Buoying.

Let us now briefly consider the buoying of a cable. In buoying a cable which is hanging from the bows, the method of procedure is similar to that employed nautically when letting go a mark or "watch" buoy.

When, however, the cable hangs over the stern, and it is necessary to pay the moorings out from forward, the matter becomes less simple. A side rope is taken round the picking-up drum, out over the bow sheave and along the ship's side to the quarter. Here it is shackled to a length of chain which passes inboard over the stern sheave, and which has shackled on to it another length of chain—the "stray chain." This in turn is shackled to a heavy mushroom anchor weighing anything between 3 and 5 cwt., according to circumstances. The free end of the chain is now secured to the cable. Inboard of this a rope is stoppered on to the cable and set taut round a large bollard. The cable is then slacked out so that the rope takes the entire weight. All being ready forward, as soon as the end of the cable has been eased out till the strain comes on the mushroom slip-rope, the rope holding it is cut, and the mushroom let go at the same moment. The ultimate result is shown in Fig. 22.

In picking up a buoy, whether serving as a simple mark buoy or as a buoy on the end of a cable, it should, if possible, be approached with the ship's head to the current or wind, and certainly never with these forces on the broadside. By the time the ship is within a hundred fathoms or so from the buoy, a boat is lowered and sent off to unrig it. Fig. 23 shows a boat going off to the *Great Eastern* for the purpose, in connection with the repair of an early Atlantic cable. This unrigging is accomplished as quickly as possible; and the ship having run up close to the buoy, the boat pulls to her, paying out a small line which is made fast to the buoy.

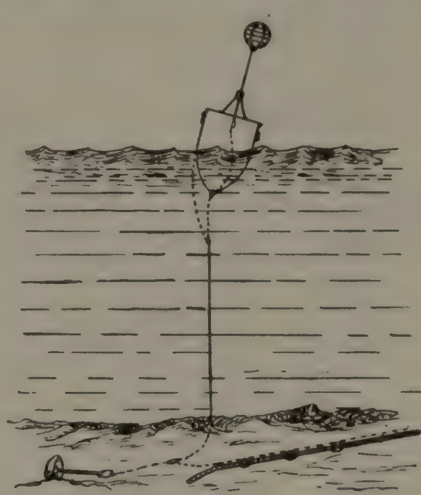


Fig. 22.—END OF CABLE BUOYED.

Having described the various implements

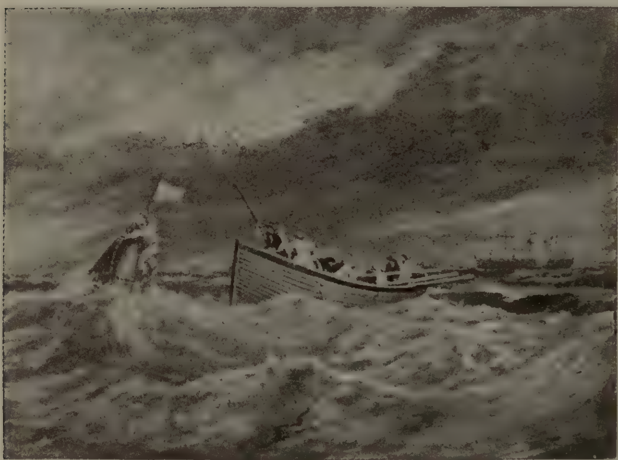


Fig. 23.—UNSHACKLING A BUOY (PREVIOUS TO PICKING UP AND GETTING IN BOARD).

involved in cable work, we are now in a position to deal with the actual laying of the line between two given spots.

Programme for Laying a Cable Section.

The vessel retained for the work first proceeds to the landing-place selected for one end of the cable. When the circumstances warrant such an arrangement, it is customary for a small auxiliary vessel to be retained for the landing of the shore ends.

Be this as it may, one shore end is first landed, and its seaward extremity buoyed at a distance of about two miles, till a depth of some twenty fathoms has been reached. The vessel now proceeds towards the landing-place selected at the other side, to land the cable there.* This end is also buoyed at a suitable point, unless, in the absence of an auxiliary vessel, the same ship is to lay the main cable. On the first supposition, the big vessel picks up the second buoyed end, splices on either intermediate or main type cable, and lays the entire line up to the farther buoyed end. This is then picked up whilst still hanging on to the main cable already laid, and after a splice has been effected between the two, the bight of cable is slipped, thereby completing the work.

* A supplementary series of soundings is often taken *en route*.

Let us now follow up in closer detail the programme which has just been briefly forecast.

Testing-Hut.

At each landing-place the end of the line is taken into a previously erected hut furnished with electrical instruments. These are for testing the cable whilst it is being submerged, exchanging signals through the line with the testing-room aboard ship, and subsequently from one shore to the other, previous to connection being established with the telegraph office in the town for the regular transmission of messages. Fig. 24 serves to illustrate the sort of erection usually set up as a testing-hut—very commonly a corrugated-iron building about twelve feet square, sent out from home in parts and put together on the spot.

Preparations for Landing Cable.

The ship that is about to land the shore end anchors opposite, and as close as possible to, the site selected for the testing-hut. A boat is then lowered and a light Manilla line run ashore to the hut. The trench for embedding the cable under the beach, if not previously opened out, should now be dug to a depth of some three

Fig. 24.—TESTING-HUT ASHORE.

or four feet, in a straight line towards the ship, from the hut to low-water mark.

There are several methods of landing the end of the cable. It will, however, be sufficient to describe that which is most favoured,

Landing Shore End.

where applicable, in modern practice; for, besides being expeditious, it overcomes certain difficulties and dangers surrounding the use of rafts, boats, etc.

This plan is due to Mr. R. Kaye Gray, M.Inst.C.E., and consists of buoying the cable at every five or ten fathoms, as it is drawn shorewards, by means of empty casks, or preferably by temporarily inflated india-rubber balloon buoys, as shown in Fig. 25.

Fig. 25.—GRAY'S METHOD OF LANDING CABLE BY BALLOON BUOYS.

In carrying out this method, the picking-up machine is usually turned to account to haul ashore the line with cable attached to it. The general scheme is illustrated in Fig. 26. Two light skeleton pulleys of large diameter (technically known as "spider sheaves") are taken ashore, where they are firmly fixed just above high-water mark—one close to the mouth of the trench, and the other about 100 yards off along the beach in one direction or the other, according to the exact position of the ship. The hauling line brought ashore from the ship's stern is now rove through the pulley nearest the trench; and after being subsequently led through the other, it is carried in a boat to the bows of the ship, where it is taken round the picking-up drum. The latter gear is then put into operation for hauling on to the line; and thus the end of the cable, securely fastened to the rope, is gradually hauled ashore. As the cable leaves the stern of the ship, the balloon buoys are attached at the required intervals. Fig. 27 depicts the operation in a completed stage, the balloons being cut away after the cable has been brought to the testing-hut. By this method the average time taken for landing the cable is some four or five hours.

The second shore end having been landed and the seaward end buoyed, the vessel with the main cable on board steams up to the buoy and proceeds to pick up the buoyed end. Having done so, a splice is effected between this cable end and that of the cable about to be laid towards the distant shore. On the completion of the splice, preparations are made for slipping the bight over the bows prel minary to paying out from the stern.

Splicing on Main Cable.

Fig. 26.—HAULING CABLE ASHORE BY STEAM.

Fig. 27.—TELEGRAPH SHIP "SILVERTOWN" LANDING SHORE END.

sinks—is sufficiently checked for it not to come seriously on the ship's stern.

For slipping the splice at the bows, the following is the usual procedure: The cable is eased away through the rope stoppers until only a small bight remains inboard. Similar outboard stoppers are then fastened to the cable on each side just clear of, and a little below, the bow sheaves. A manilla rope is next led from the drum of the picking-up machine, and, threaded through the end of the outward stopper, is made fast to bollards at the bows. When this has been done on each side of the bight, the drum ropes are hove tight on board and the inboard stoppers loosened. A heaving-line is next run through the bight to guide and steady it over the bows. The drum ropes are then slackened away, thus gradually lowering the bight of cable into the sea. As soon as the bight has reached the position illustrated by Fig. 29, the heaving-in line is run clear of the cable; and when sufficient length of drum rope has been paid out, the ends fast to bollards are let go, and the ropes run clear through the outboard stoppers.

Having successfully passed the cable outboard, and the ship being suitably handled, the line leads out from the stern. The vessel forthwith sets out on her course for the proposed route, and paying out is proceeded with.

When a cable is laid at a uniform speed, on

Before effecting the splice, the top end of the cable in the tank to be paid out from is secured in position and threaded through the paying-out machinery aft, ready for laying. From here it is led outside the ship, and a sufficient length brought inboard again over one of the bow sheaves, for the purposes of the splice with the shoreward end. All this is shown in Fig. 28.

During splice-making each cable is kept securely "stoppered" at the bows. In preparing to slip the bight over the bows, men are stationed at suitable distances along the ship's side with hand slip-ropes, the bights of which suspend the cable over the side, as may be seen in the illustration. When the splice is let go over the bows, the strain is taken up by these hand slip-ropes, the ends of which are let go successively as the strain comes on them in turn. By this means the strain—due to the weight of the cable as it

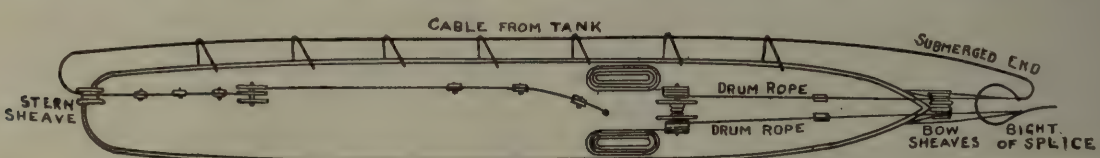


Fig. 28.—PREPARATIONS FOR SLIPPING SPLICE FOR PAYING OUT FROM STERN.

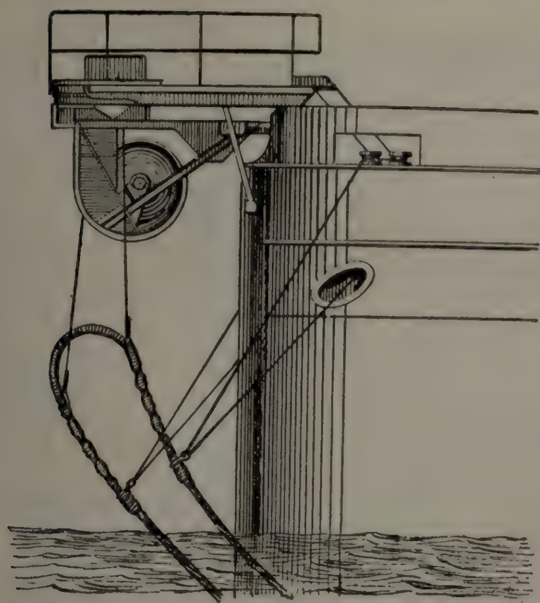


Fig. 29.—SLIPPING BIGHT AT BOWS.

a level bottom, quite straight but without tension, it forms an inclined line towards the position of the bottom that it ultimately occupies—precisely the movement of a battalion in line changing front. Again, when paying out cable in an ocean depth of three miles, it is calculated that, with the ship steaming eight knots, the length from the stern of the vessel to the spot where it touches the ground is over twenty-five miles, and that it takes a particular point in the cable more than two hours and a half to reach the bottom from the time it first enters the water.

Laying Main Cable.

As has already been indicated, in order to provide for the declivities of the bottom, a certain length of spare, or "slack," cable requires to be paid out beyond that which would be involved by the distance overground. The slack cable actually so paid out will be inversely proportional to the square of the ship's speed, and depends, firstly, on the weight of a length of cable sufficient to reach the bottom vertically; and, secondly, on the holding-back force. It can in fact, be varied either by regulating the brake force or changing the speed of the vessel; but the former plan is more immediately effective.

The average slack with which the cable is to be laid is generally arranged beforehand. It is well never to let it fall appreciably below five per cent., and it should be increased to ten per cent. (or more, if necessary) over a sloping or irregular bottom.

The speed of the ship during laying being usually from six to eight knots, tables are calculated in advance corresponding to different rates of speed within these limits, giving, for about every 50-fathom depth, the load to be placed on the brake levers, in order to lay anything between five and twelve per cent. slack. With these tables the slack is readily regulated, provided we know the depth and the speed of the ship overground with sufficient accuracy. A development of this in modern practice is to pay out a small steel wire without slack, and by comparison with this to regulate the paying out of the cable. This plan was due to that distinguished electrical engineer the late Werner Siemens.

The soundings taken previous to laying the cable should be numerous enough to give a tolerably exact profile of the bottom between the two landing-places. The track of the cable is naturally plotted on a chart, and the positions of the ship at any time are, of course, fixed by astronomical observation as occasion offers. Recourse has also to be made to the ship's log and the revolutions of the propeller for estimating the distance covered by the vessel, and so also helping to give the "dead reckoning" position at any moment.*

* Though some of the larger vessels are capable of holding upwards of 1,000 miles in each tank, it is usually necessary to perform the operation of "changing tanks" during the laying of a long line. That is to say, the cable in one tank being exhausted, that in another has to be turned to. It would be beyond our scope to deal with the full routine of this somewhat delicate operation. It was, however, described in detail by the author in his recent lectures to the Royal Naval War College, Portsmouth, as well as previously in those delivered to the Royal Engineers at Chatham, since duly published.

On arriving within sight of the distant buoyed end, the ship is gradually slowed down and stopped as near to the buoy as possible, the cable being allowed to run out till it hangs almost vertically from the stern. Meanwhile a stout line has been passed from the picking-up drum round the ship's side to the stern. When it has been securely "stoppered," the cable is next cut abaft the paying-out drum, and after being made fast to the line is led round to the bows by the picking-up gear.

Picking up Farther Buoyed End.

The shoreward end is then detached from its buoy and picked up on one of the other bow sheaves, the buoy being taken inboard at the same time. The shoreward end is next tested through, and if the electrical condition of both this and the main cable is quite satisfactory, a splice is at once effected between them.

Two new hempen ropes are then secured (as shown in Fig. 30) to the bight of the cable a few fathoms on either side of the splice, and the ends of these ropes taken round the two picking-up drums, one round each. Both drum-ropes, holding on to the two sides of the bight, are now eased away through the stoppers till their fastenings with the cable reach the baulks. Two thimbles are next secured, one to each leg close inside the bow sheave, ropes being passed through them, and the two parts of each brought round outboard over both bows. One of the two ends on either side is secured to bollards on the forecastle, the other being passed in through hawse-pipes, and there kept well in hand. Both drum-ropes are now slowly paid out, the legs of the cable being eased through the stoppers, and seized to the drum-ropes as they go out. The slip-ropes are also eased out as required.

All this time the bight is being carefully tended by several men, who stand by till the time is ripe for passing it over the bow sheaves. The procedure is, indeed, very similar to that described for passing the bight from the bows to the stern.

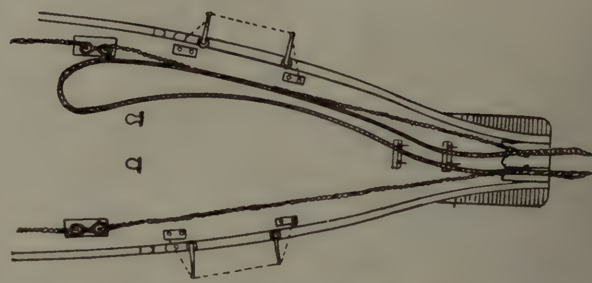


Fig. 30.—PREPARING TO LET GO FINAL SPLICE AND BIGHT.

Slipping Final Splice.

When the bight is well below the bow baulks, the ship is put astern, and both drum-ropes cut simultaneously. The bight should then have found its way to the bottom, thereby bringing to a successful close the laying of the entire cable, involving a good deal of arduous work, not unmingled with anxiety.

Throughout the laying of the line a continuous electrical test is, as has been shown in the previous article, kept on the cable from the ship. This test is for ascertaining

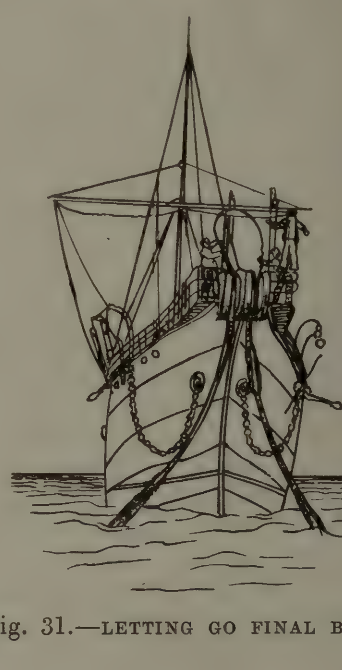


Fig. 31.—LETTING GO FINAL BIGHT.

Fig. 32.—TESTING-ROOM ABOARD SHIP (T.S. "COLONIA").

that continuity is maintained from end to end, and that the electrical insulation is satisfactory. In addition to this, signals are exchanged, at pre-determined time intervals, between the ship and the shore hut from which the cable has been laid. Occasional brief messages are also included in the routine.

Electrical Testing.

CONCLUSION.

The World's Cable System.

Perhaps the most recent striking development in submarine telegraphy is the All-British Pacific Cable, in deep water, far distant from trade routes or foreign shores. This runs into depths of four miles in places; and just as the first Atlantic cable was considered at the time "a wild freak of people that were to be pitied," so also this first Pacific cable was similarly spoken of by some, mainly on account of the great length (3,458 nautical miles) of one of its sections. It was, however, laid (in 1902) without a hitch.

The useful life of a cable may be nowadays as much as forty years, after which it is usually better to replace the line than to attempt to again repair it.

In the present day cables have no history. It must not, however, be supposed from this that we do not have occasional minor mishaps nowadays. Moreover, even though our materials are so vastly superior to what the pioneers had at hand, there are still the usual eventualities, many of which, as has been shown, are scarcely under control.

By far the greater proportion of the cables

at the bottom of the sea have been manufactured and laid by British contractors; but France, Germany, and Italy all now have their cable works and ships, whilst Japan will no doubt shortly.

The statistics below present a few facts of general interest in connection with this very wide subject, which it has only been possible to deal with cursorily in the course of these pages.

APPROXIMATE STATISTICS.

Total length of cable laid	257,000 miles.
Total cost of cable laid	£52,000,000.
Cost per mile (construction and laying)	£200.
Useful life of a cable	30 to 40 years.

The author is not one of those who believe in the early consignment of cables to the region of antiquarian museums, though having great belief in the utility of wireless telegraphy for all maritime purposes and as a helpmate to our cable system, especially in cases where cables are ineffective. Certainly so far there are no signs of cables being replaced by wireless telegraphy when further means of communication are required; and, as a matter of fact, over 85,000 miles of cable have been made and laid since the Marconi Company was first established twelve years ago—more than five times as much, indeed, as was made and laid during the twelve previous years.

At the moment telegraphy by cable bears much the same relation to radio (wireless) telegraphy as steam navigation does to sail navigation in the matter of speed and reliability.

COMMERCIAL CABLE COMPANY'S STATION AT WATERVILLE (GENERAL VIEW.)

Some idea is given here of an Atlantic cable station of to-day. In this instance it amounts to a cable colony—practically constituting the town.

THE MODERN DESTRUCTOR.

BY F. L. WATSON, M.I.Mech.E., A.M.Inst.C.E.

THE disposal of the rubbish of cities by burning was known and practised by the ancients, a fact which can be proved by many classical and Biblical quotations. During the Dark Ages, however, all systematic sanitary work fell into disuse, and the disposal of refuse was left to the individual, who easily solved the difficulty by depositing it in the public street.

When modern civilization brought with it the organization of public cleansing, in some countries the system was adopted of appointing a public contractor, who had a right to charge each householder for the removal of his rubbish ; in others the householders united to employ their own contractors; and in others, again, the municipality undertook the collection and disposal of rubbish either by employing a contractor or by using its own means of transport and employing direct labour.

Collection and disposal by the municipality is now the general rule in England and in Germany, and to a great extent in France ; but in the United States collection and removal by contractors is prevalent.

The Old System of Disposal.

Until quite recently it was the universal custom of municipalities to deposit the rubbish thus collected in tips, using it to fill up old brick pits and hollow spaces, and for raising and reclaiming waste or marshy land. Where suitable land is available a great deal of town refuse may be usefully employed in this way, provided the distance is not too great ; but the tipping of refuse in any area included in the possible growth of a city, and which may become building land, ought to be entirely prohibited, because this material will for many years go on fermenting and producing noxious germs whose deleterious action can only be prevented by the natural process of growing crops on the surface.

It is evident, therefore, that municipalities, especially of large cities, are being more and more driven to adopt the complete and final disposal of their rubbish by the most ancient and perfect of purifying agents — namely, fire.

When special furnaces were first introduced for this purpose in England they were very crude affairs, erected by the local bricklayer without any regard for the science of combustion. In due course, however, the designing and building of destructors became recognized as an important branch of engineering, and there are now a number of engineers who devote all their attention to this subject. The result has been that the destructor of to-day has become a highly scientific and very useful apparatus, and one in which enlightened municipalities are prepared to invest very large sums of money.

Forced Draught.

The most important step on the upward march occurred when the principle of forced draught, embodied from time immemorial in the blacksmith's fire, was applied to the destructor. The immediate result was to produce rapid combustion and a high temperature, and to prove that all classes of ordinary town rubbish are, with very few exceptions, auto-combustible or capable of burning without added fuel. The high temperature produced by this improvement led to the idea that the heat evolved could be utilized, and this was done by putting a small boiler in the flue of the destructor and using the steam

generated to produce the forced draught for the furnace.

Continuous improvements in the furnaces have entirely reversed the proportions of the furnace and the boiler, and whereas in the early days a boiler of 25 or 50 horse-power was considered sufficient for a row of eight or ten large furnaces burning at a comparatively slow rate, we now find boilers of 200 or 300 horse-power attached to a battery of two or three furnaces, the boiler taking up almost as much room, and costing almost as much money, as the destructor itself.

So far from merely providing the steam for their own forced draught, modern destructors produce a vast surplus which is used for many purposes, the production of electric light and power being one of the most important.

Striking examples of such destructors on modern lines may be found in Liverpool, Nottingham, Glasgow, Greenock, London, and many Continental towns and cities. Some of these plants are provided with a complete electrically-driven equipment for handling the refuse, so that there is neither raking, shovelling, nor handling of the material by the workmen until after it has passed through the purifying process of fire.

We describe as an example a plant recently erected at Greenock, and may mention that plants on precisely similar principles have been erected in the borough of Poplar, London, and the cities of Melbourne (Australia), St. Petersburg and Warsaw (Russia), and Zürich (Switzerland).

Greenock Plant.

The plant at Greenock will serve as a type of the rest. This consists of six cells or furnaces, divided into three batteries, each battery consisting of two cells, and having attached to it a water-tube boiler of 250 horse-power. Forced draught is produced by means of electrically-driven high-pressure fans, which draw the air from various parts of the building where ventilation is required, and, after preliminary heating, blow it into the ash-pits of the cells. An air pressure equal to about five inches water column of water is maintained under the grate. The rate of combustion is about 100 lbs. per square foot of grate per hour, which is about double the rate usually obtained in the boilers of battleships under forced draught, this with a fuel consisting entirely of rubbish, and popularly supposed to contain nothing of value whatever.

The steam produced is sufficient, when used in engines of a modern type, to produce about 100 electrical units (kilowatt hours) for every ton of refuse burnt. In other words, from six to seven tons of refuse produce an amount of steam equivalent to that obtained by burning a ton of good coal.

Automatic Stoking.

The stoking of these furnaces is done by means of an overhead electric crane. The carts, on arriving at the destructor, tip their contents into a series of boxes, each capable of holding from one to two cart loads. As the carts come in at irregular times, and the refuse has to be burned with strict regularity, these boxes are kept ready filled until needed, and are then lifted by the crane, and placed in a cradle on the top of the furnace, so arranged that the weight of the box opens the door of the furnace, thereby permitting the contents to be dropped bodily into the destructor, the door being automatically closed by the lifting of the box. When closed, the furnace door is sealed by dipping into a water trough on the same principle as the ordinary gasholder.

The labour of the furnacemen is thus confined to the removal of incombustible residue from the destructor. This residue, known as clinker, consists chiefly of silica, and is broken up for making concrete, ground up with lime to make an excellent mortar, or used after fine grinding and mixing with a small proportion of lime in the manufacture of artificial bricks, or (using cement instead of lime) for the manufacture of paving flags.

RUNNING LEAD INTO JOINTS. *(Photo, by courtesy of Messrs. James Simpson and Company, Limited.)*

THE COOLGARDIE AQUEDUCT.

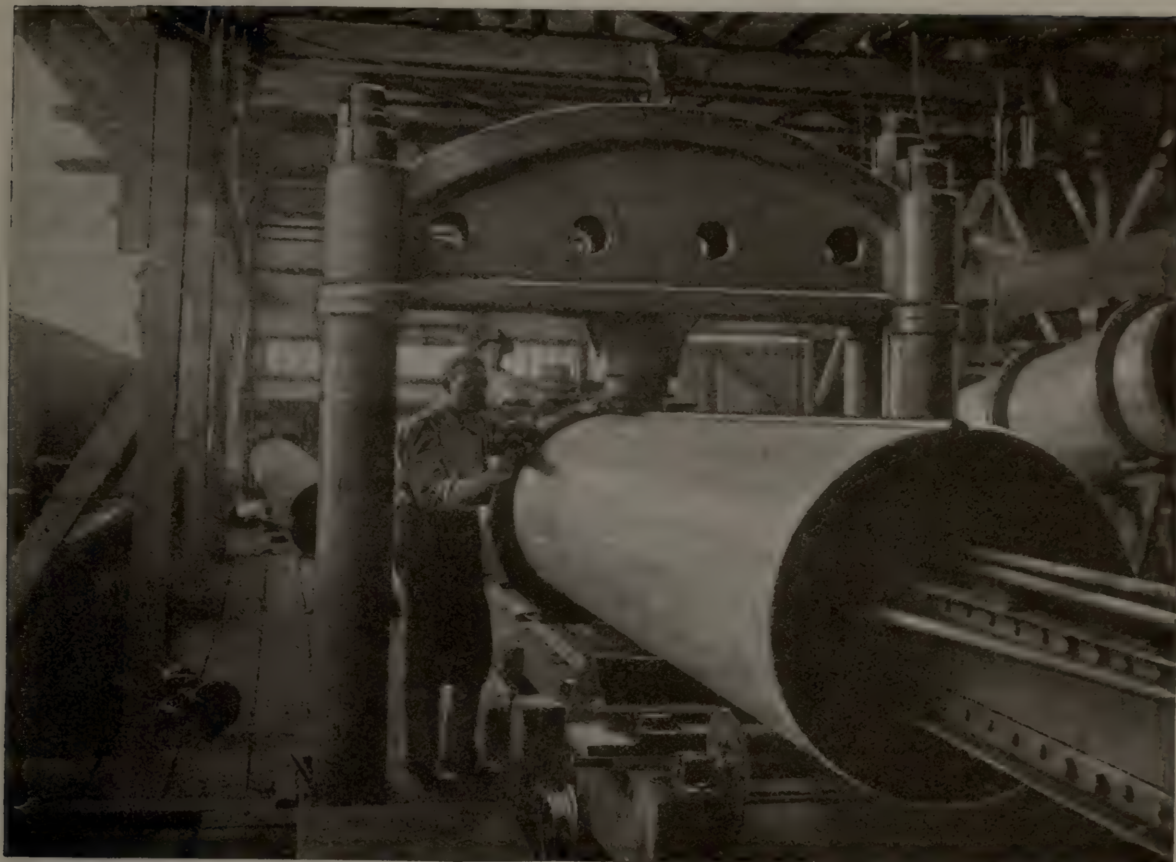
The Longest Aqueduct in the World, and, apart from its length, one of the most remarkable.

THE aqueduct which forms the subject of this article is as undoubtedly one of the greatest engineering schemes carried through on the Australian continent as it is the longest aqueduct in the world. The fact that the volume of water delivered by it daily is small as compared with the quantity passed by other aqueducts noticed in previous articles is more than counter-balanced by the peculiar difficulties with which the engineers had to contend.

A Water Famine in the Goldfields.

In 1892 the great Coolgardie goldfield of Western Australia was discovered by prospectors, who had spread over the country from the then terminus of the railway at Southern Cross, some 235 miles from the coast. The remaining 130 miles to the goldfields had to be covered in the rough and ready way which characterizes a "rush." A population sprang up quickly in a district wherein good drink-

LOWERING PIPE INTO TRENCH.



CLOSING 30-INCH LOCKING-BAR PIPES IN HYDRAULIC PRESS. (*Photo, Messrs. Mephan-Ferguson, Limited.*)

able water, necessary for the maintenance of health, and even water of any kind for mining purposes, was remarkably scarce, as the little rain that fell was quickly absorbed by the, in most places, very porous and saline surface soil. The washing-out of gold being impossible in such circumstances, the miners resorted to the "wind-blowing" system of separating alluvial gold dust from the dross, letting the stuff fall from one pan held aloft into another resting on the ground, and trusting to the force of the wind for the removal of the light rubbish.

The lack of potable water caused epidemics of typhoid fever, so serious as to compel the Government to spend considerable sums on well-sinking—unfortunately without success—and on the construction of tanks and dams and distilling installations. In those days, long after Coolgardie had begun to look like a prosperous town, water fit for drinking retailed at half a crown per gallon, and the saying ran that in the saloons the bartender watched the water-bottle more carefully than that which held the whisky.

Fabulous Prices for Water.

Meanwhile the railway had been extended from Southern Cross to Coolgardie and Kalgoorlie; but the railroad authorities soon found that, owing to the shortage of water, they could not run their trains at a profit—the water alone cost them some hundreds of pounds a day. As the population depended for its supplies on the railway, this additional difficulty brought matters to a crisis, and laid on the Government the task

Railway Needs.

of devising some scheme for supplying good water in an adequate volume and at reasonable prices. Orders to report on practicable schemes were issued, and after several months of surveying and estimating Mr. C. G. O'Connor, M.Inst.C.E., laid before the Government the three best out of thirty-one alternative proposals. Of these three, the one to supply 5,000,000 gallons per day, through a steel pipe 30 inches in diameter, was selected as the basis of the final scheme.

Government takes Action.

The supply reservoir would be formed by damming the Helena River in the Darling Range, at Mundaring, about 20 miles from Perth. The catchment area was 569 square miles in extent; and the authorities decided to provide sufficient storage to meet the waste and use of two years in time of total drought.

The Scheme.

From the reservoir the water would be led by pipes to Kalgoorlie, over 350 miles away, passing through Coolgardie *en route.* Two great difficulties faced the engineers. The first was that the reservoir had an elevation of but 340 feet above sea-level, whereas Kalgoorlie lay about 1,000 feet higher still; while in between were ranges of hills to be crossed, one of them rising to nearly 1,600 feet above the sea. So that, instead of flowing by gravitation, as is the case in all other large aqueducts, the water would have to be *forced* from point to point for the greater part of its journey against a total resistance—allowing for frictional resistance—equivalent to a single lift of about 2,650 feet. In order to bring the pressures within practicable limits, it would be necessary to divide the pipe line into sections between the main storage reservoir and the highest point on the route; and to provide at the western end of most of the sections a powerful pumping installation, drawing its supply from a stand pipe or a regulating tank.

The second difficulty related to the question of the best kind of pipe. Cast-iron pipes were put out of court by the cost of sea and land carriage. It was necessary that the pipes should be of steel, for lightness' sake, and of such a type as to occupy a minimum space aboard ship. Tenders were invited from Australia, Europe, and America, and eventually the Mephan-Ferguson patent locking-bar pipe was adopted. The pipe consists of two steel plates, each of the full length of the pipe and bent to a semicircular form. The beaded edges of the plates are inserted in long bars having deep grooves on either side; and the bars are closed cold over the beads by powerful hydraulic presses. The pipes for the Coolgardie aqueduct were assembled in Western Australia out of plates imported from Germany and America and bars shipped from England. Every pipe, after being assembled, was subjected, in a special apparatus, to a hydraulic pressure of 400 lbs. to the square inch, and returned to the closing machine for re-pressing if it showed the least symptom of leakage. It is an interesting proof of the efficiency of the locking-bar system that only about fifty out of the 60,000 pipes required for the line failed to pass this test.

Pipes.

The Locking-bar Pipe adopted.

The site of the containing dam for the storage reservoir being some miles from the nearest railway, a light line was built to connect it with that railway. August 1898 saw the completion of this preliminary work. In April 1899 excavations for the foundations of the dam commenced. On being opened up the rock was found to be far less solid than trial pits had led the engineers to think it would be. A great fissure, running at right angles to the axis of the dam, was discovered; and, as the site could not be changed, the miners had to follow this fissure to sound rock, some 90 feet below the river bed. The foundations were formed of concrete to bed-

The Helena Dam.

level on the up-stream face, but only to within 18 feet of the bed on the lower side; and on them was raised a concrete dam, 760 feet long and 100 feet high above the river bed, tapering in thickness from a maximum of 120 feet to 15 feet at the crest. Nearly 70,000 cubic yards of concrete were consumed in its construction. A draw-off valve tower is situated on the reservoir side of the wall, into which it is built; and a scouring valve tower rises at a point 175 feet below the dam. Provision is made for drawing off water at three different levels through screens, which can be removed for cleaning.

The Helena dam, completed in June 1902, impounds a reservoir which, when full, contains about 5,000,000,000 gallons of water.

Operations connected with the laying of the pipe line were commenced in March 1900. To facilitate transport of materials the route of the aqueduct followed closely for the main part that of the Coolgardie railway.

The Aqueduct.

Where the ground was soft and not saline, the pipes were buried; in rock and hard ground, shallow trenches below and embankments above were used; and across salt lakes or their dry sites the pipes ran on trestles, an insulation of sawdust, kept in place by galvanized corrugated iron, serving as protection against heat and cold. Where possible, the ground was loosened by horse-ploughs to reduce the amount of manual labour required. One-fourth of the total material removed had to be blasted. To promote speed, the trenching was begun at several points simultaneously, and in each section kept well ahead of pipe-laying.

All the pipes were distributed by means of the railway. Two cars, coupled together, carried eight pipes, three in each of the two bottom tiers and two on top. Eighty-eight to one hundred and four pipes made up a train-load. Twenty-four men, divided into four gangs, could unload the pipes in about an hour. When not engaged in this work the same men busied themselves with the trench digging, matters being so arranged that no time should be wasted.

Pipe-layers at Work.

The pipes, laid out in their respective positions beside the trench, were taken in hand by successive gangs. First came the repairers, who made good any defective areas of pipe coating; behind them the men who scraped off a ring of the coating for six inches at each end of every pipe, and chipped the ends of the locking-bars. Next in order were the manhole-cutters; followed by the pipe-layers, who, with the aid of steel trestles spanning the trench and of winding gear, lowered the pipes into place. Then came the ring-setters, the lead-runners, the hand caulkers, and, last of all, the gang in charge of the mechanical caulking-machine.

Mechanical Caulking-Machine.

This device merits a few words to itself. A caulking installation included a portable oil-engine, working a dynamo, from which current was led through a cable to a motor on the machine. The caulker was in two halves, separable to permit them to embrace the main. The motor, attached to the top half, drove the racks operating the steel rollers which forced the lead tightly, but evenly, into the joints at either end of the joint ring. Five semi-revolutions of the rollers usually sufficed to make the joint staunch. Knives were then substituted for the rollers to pare off the lead flush with the rings. As soon as the joint had been "passed" by an inspector the trench was partially filled in, completion of this work being reserved for a gang in rear of the machine. About half a mile of pipe could be thus caulked without moving the generating plant to a fresh position. Good organization and increasing skill enabled the seven gangs to lay, joint, and cover up nearly $1\frac{1}{2}$ miles of pipe per day of eight working hours. In 1901, 90 miles of

aqueduct was completed, and the remaining 260 miles in the following year.

Pumping Stations and Reservoirs.

The first of the pumping stations is located about a furlong below the Helena dam. It lifts the water through $1\frac{1}{2}$ miles of pipe, against a head of 415 feet, into a concrete receiving tank. Close to this is station No. 2, which raises the water another 340 feet to a concrete regulating tank at Baker's Hill, $22\frac{1}{4}$ miles eastwards. From this tank the water gravitates to West Northam regulating tank, 12 miles distant; and from it to Cunderdin reservoir—another 41 miles—three-quarters of a mile beyond which is pumping station No. 3. The water then gets six successive lifts at stations Nos. 3, 4, 5, 6, 7, and 8, of 215, 333, 52, 106, 56, and 183 feet respectively, to the great main service reservoir at Bulla Bulling, $306\frac{1}{2}$ miles distant from the Helena dam. From this reservoir, which has a capacity of 12,000,000 gallons, the water gravitates to the Coolgardie and Kalgoorlie service reservoirs, which hold one million and two million gallons respectively.

At all of the eight stations the pumping plants are practically identical, except for the diameter of the pump-plungers. The engines, built by Messrs. James Simpson and Co., Ltd., of London and Newark, are of the Worthington duplex six-cylinder, triple-expansion type, with Corliss valve gear.

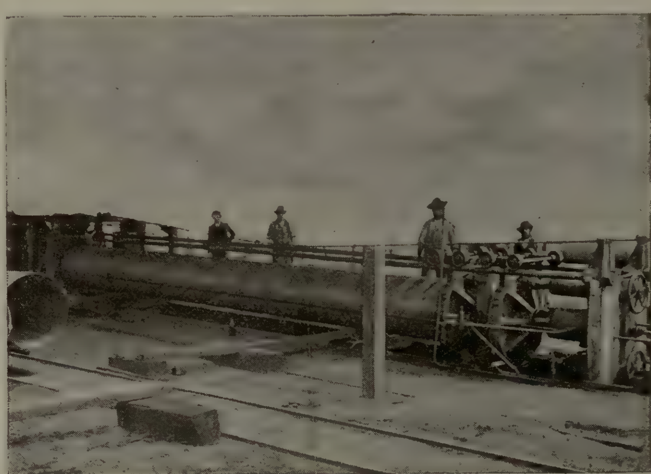
The Pumps.

Great care was needed, when packing the machinery for export, to avoid mistakes, and to ensure that every one of the twenty groups of machinery should arrive complete at its proper station. Each group was therefore given a distinctive colour and letter, and every part painted with the colour of the group to which it belonged. As a result of these precautions only a single $\frac{1}{2}$-inch hydraulic valve was reported missing out of some five thousand packages transported from England to various points along the pipe line.

Filling the Main.

By the middle of April 1902 pumping began at station No. 1, and on the twenty-second day of that month water reached the Cunderdin reservoir, at mile 77. As each section was completed the water resumed its wonderful journey into the heart of the arid region. December 22, 1902, was a red-letter day for Coolgardie, for it witnessed the arrival of the supply which should thenceforward guard the citizens against the dangers and discomforts of shortage; and within a month the Kalgoorlie miners also were enjoying the use of water that had travelled a distance equal to that separating London from Edinburgh.

The total cost of the scheme was £2,660,000, of which sum the aqueduct accounted for £1,870,000, or £5,312 per mile.



TESTING LOCKING-BAR PIPES WITH HIGH-PRESSURE WATER.
(Photo, Messrs. Mephan-Ferguson, Limited.)

END OF VOLUME III.

GENERAL INDEX.

A

Abernethy, James, I., 154.
Adamson, Daniel, I., 153.
AERONAUTICS:
The Aeroplane, Theory and Principles of, III., 5–13.
Lessons from the kite, 5; "drift" and "lift," 5; experiments with gliders, 6; shape of supporting surfaces, 6; action of air on curved aeroplane, 7; disposition of planes, 7; monoplanes and biplanes, 7; "aspect ratio," 7; considerations regarding the design of an aeroplane, 8; power needed to support an aeroplane, 8; maintenance of STABILITY, 9; centre of pressure, 9; front elevators, 9; automatic stability, 11; fixed tails, 11; rear elevators, 11; lateral stability, 11; Voisin vertical curtains, 12; various auxiliary devices, 12; Wrights' apparatus for maintaining stability automatically, 12; the gyroscope a possible means of stabilizing, 12; influence of speed on stability, 12, 13.
Flying Machines of To-day, III., 15–28.
The term aeroplane, 15; the Wright brothers, 15; experiments with gliders, 15, 16; an engine fitted to a glider, 16; first great human flights with "White Flier," 17; record-breaking flights in France (1906), 17. WRIGHT BIPLANE described, 17, 18; steering and balancing, 18; engine and propellers, 19; how the machine is started, 19. VOISIN BIPLANE, 21; steering control, 21. FARMAN BIPLANE, 23. CURTISS BIPLANE, 24. CODY BIPLANE, 24. BLÉRIOT MONOPLANE, 25, 27. ANTOINETTE MONOPLANE, 27. R.E.P. MONOPLANE, 28.
Aeronautical Engines, III., 29–37.
Need for very light but powerful engines; Maxim's and Langley's experimental engines, 29; need for reliability, efficiency, and automatic action, 29; how weight is saved, 30; automatic lubrication, 30; carburation, 30; possible decrease in weight, 30. FOUR-CYLINDER ENGINES: Wright engine, 30, 31; Green, 31, 32. THREE-CYLINDER ENGINE: Anzani, 32. SEVEN-CYLINDER ENGINES: Gnome, 33, 34; Clément-Bayard, 34, 35; R.E.P., 35. EIGHT-CYLINDER ENGINES: Antoinette, 35; Wolseley, 36; Fiat, 36; Jap, 37; Pipe, 37; Gobron, 37.
Construction of Aeroplanes and Aerial Propellers, The, III., 39–44.
An aeroplane not so simple to construct as its appearance suggests, 39; woods used, 39; decks, single and double surfaced, 39, 41; uprights, wire stays, body work, chassis, 41; screw propellers—thrust, 42, 43; slip, 43; materials and manufacture, 43, 44.
Dirigible Balloons, III., 45–63.
Terminology — "airships" and "flying machines," 45; shape of gas-holders, 45; prows and sterns, 47; resistance to the air, 48; pressure on the envelope, 48; Zeppelin principle of subdivision, 48; ballonets, 48; distribution of the load, 48; application of power, 48; stability, 49; steering, 49. DEVELOPMENT OF THE AIRSHIP: Giffard's dirigible, 49; Dupuy de Lôme, 51; Renard and Krebs, 51; Santos Dumont and the Deutsch Prize, 51; "Zeppelin I.," first trials, 52, 53; "Zeppelin II.," a disaster, 53; "Zeppelin III.," "Zeppelin IV.," 53; a trip over Switzerland, 53; voyage ends in disaster, 55; a record journey of 600 miles, 55; collision with a tree, 55; (French dirigibles) Lebaudy airship, 56; "La Patrie" and "La République," 56, 57; "Ville de Paris," 57, 58; "Clément-Bayard I.," 58; "Clément-Bayard II.," 59; (German military dirigibles) the Parseval, 61; the Gross, 61; (American) the Baldwin airship, 62; materials used for gas bags, 62; the dirigible in warfare, 62, 63; Sir Hiram Maxim's estimation of its value, 63.
Records of Aviation, III., 44.
Records of Dirigible Balloon Flights, III., 64.
African Transcontinental Telegraph, The, I., 193–204.
Originated by Cecil Rhodes, 193; construction company incorporated, 194; line erected for 200 miles, but destroyed in Matabele rebellion, 194; work recommenced along different route, 195; negotiations with Germany, agreement made, 195; labour and climatic conditions, 196; proposed route of A. T. T. north of Udjidji, 196, 197; physical obstacles encountered by the engineers, 198; a huge span, 198; the telegraph poles used, 199; attitude of the natives, 199; measures for preventing injury to the line, 199; damage done by wild animals and by vegetation, 200, 201; health of the constructors, 201; commercial success, 201; wireless telegraphy suggested to bridge gap in line, 202; police patrols, 202; a stirring incident, 203; table of distances, 204.
Agamemnon, H.M.S., used for laying first Atlantic cable, II., 285, 286, 288, 354, 356–360.
Agricultural Engineering, III., 288–299.
The importance of agriculture, 288; value of labour-saving agricultural machinery, 288. STEAM TILLAGE: John Fowler's single engine plough tackle, 289; double plough system, 289; advantages of deep ploughing, 290; ploughing engines, 290; "balanced" and "turn-round" ploughs, 290, 291; special ploughs—a heath plough at work, 291, 292; drainage of swamps by ploughing, 292; the Mole drainer, 292, 293; seeding and planting machines, 293; reaping machines—M'Cormick's reaper and its development, 293, 295; the self-binder, 295; the threshing machine, 295; mammoth reapers, 297; enormous steam tractors, 298. AGRICULTURAL OIL MOTORS: their advantages, 298, 299; Ivel motor, 299.
Air-lift, for raising petroleum, II., 336; for raising water, III., 345.
Air-locks, I., 58; principle described, 304, 305; for Runcorn Bridge foundation cylinders, 294, 298.
Alfred the Great as shipbuilder, I., 313.
Alpine Mountain Railways, Two Remarkable, III., 300–311.
THE FELL RAILWAY: schemes for a line over the Alps, 301; the Mont Cenis road, 302; the Fell system track and locomotive, 302; brakes, 302; locomotive tested on High Peak railway, 302; concessions granted for Fell railway, 303; preliminary experiments carried out, 303; construction begun, 303; difficulties encountered, 303; very sharp curves, 304; snowstorms and snow-sheds, 304, 305; line completed, 304; short but useful life, 304; economy of the system, 305; project for another surface railway over the Alps, 306. THE JUNGFRAU RAILWAY: M. Adolph Guyer Zeller's scheme, 306; the stations on the line, 307; a railway in tunnel, 307; electric drills used for boring, 307; surveying the route, 307; track and locomotives, 309; Eigergletscher station, 309, 310; rough weather in winter, 310; Eigerwand station, 310; Eismeer station, 311; conclusion, 311.
Alternating current, III., 227.
Aluminium: conductors, III., 273; decrease in price of metal, 272; separation in electric furnace, 273; uses of metal, 272.
Anchorages: Grand Trunk Railway Bridge, III., 281; Menai Straits Bridge, I., 143; Niagara Falls and

Clifton Bridge, III., 283; Williamsburgh Bridge, II., 264; Zambesi Bridge, I., 97.

Ancient Engineering, I., 5–20.
The engineer a great historian, 5; Stonehenge, 6; the stone "lines" of Carnac in Brittany, 7; colossal Egyptian statues, 8; Great Pyramid of Cheops, 9; great stones of Baalbec, their wonderful finish, 10; how did the ancients move great masses of stone? 11; a suggestion, 13; Herodotus on the building of the Pyramids, 14; was an inclined plane used for the Pyramids? 14; useful engineering feats, 14; Roman sewers, 16; Roman aqueducts, astonishing figures, 16, 17; Roman hydraulic science, 17; Roman roads, 18; Hezekiah's tunnel, 19; great Roman tunnels, 19; tools of the ancients, 20; a Roman metal screw, 20; conclusion, 20.

Ancient tools, I., 19, 20.

Ancients, how they moved great weights, I., 11, 13, 14.

Anderson, James, designs a Forth Bridge, I., 322.

Angara river, I., 69.

Angara train ferry, I., 78.

Antoinette monoplane, III., 27.

Appold, J. G., inventor of the self-releasing brake, II., 291.

AQUEDUCTS:
Barton Swing, over Manchester Ship Canal, I., 163, 165; British, *see* "Great British Dams and Aqueducts," III., 177–192; Catskill, III., 107–111; Derwent, III., 192; Elan-Birmingham, III., 189, 191; Glasgow, III., 179; Kinlochleven, III., 275; Modern, principles of, III., 179; New Croton, II., 105; III., 99, 100; Old Croton, III., 98, 99; Roman, I., 16–18; III., 177; Solani, III., 242; Thirlmere-Manchester, III., 183–189; Vyrnwy-Liverpool, III., 180, 181, 182, 184.

Arch, St. Louis Bridge, II., 170.

Arch Bridges at Niagara Falls, The, III., 278–287.
List of bridges built across Niagara gorge, 278; need for replacing the GRAND TRUNK RAILWAY BRIDGE, 279; a steel arch bridge designed, 279; abutments and skewbacks, 279; anchorages, 281; adjustment toggles, 281; travellers for handling material, 282; bridge tested, 282. NIAGARA FALLS AND CLIFTON BRIDGE, 282; its huge arch span, 282; details of bridge, 283; clauses in contract specification, 283; difficulties to be overcome, 283; method of erecting the arch, 283; anchorages and anchorage bars, 283; foundations built, cantilevers commenced, 284; handling material, 284; interference of new arch with old bridge, 285; climatic obstacles, 285; quick construction, 287; an ice jam and its results, 287.

Arkansas river, II., 90.

Armament of a Battleship, The, I., 404–417.
Main armament, 404, 407–412; secondary armament, 405, 413, 414; tertiary armament, 415; wire-wound guns, 408; breech-block action, 408; absorption of recoil, 409; gun mountings, 409; erosion and wash, 410; firing a gun, 410; turrets and barbettes, 411; ammunition hoists, 411; a colossal gun, 413; 6-inch gun mountings, 414; anti-torpedo craft armament, 415; disposition of armament, 416; various systems, 416, 417.

Armour of a Battleship, The, I., 397–403.
Early armour, 397; the *Warrior*, first British ironclad, 399; compound armour, 399; Harvey and Krupp processes, 399; manufacture of steel, 399, 401; how armour is supported or backed, 401; fixing armour to backing, 401; armoured decks, 402; capped shells and their penetrative power, 402; "Era" steel and reinforced concrete armour, 403.

Armoured decks, I., 402.

Arnodin, F., I., 289, 291.

Artesian Wells, and How They are Bored, III., 335–346.
Ancient wells, 335; artesian wells, 335; rainfall, subterranean streams, and springs, 336; dug wells, their defects, 336; lining artesian wells, 337; boring tools—chisels, ropes, and rods, 337; the diamond drill, 338; the calyx drill, 338; the shot drill, its principle, 339; detaching cores, 339; retrieving broken rods, 340; blasting, 341; rescuing and cutting pipes, 342; a curious case of flints cutting tools, 342; American wells, 343; a great artesian area in the United States, 343; power from wells, 343; Australian wells, 344; sinking a well, 344; the air-lift, its principle, 345; disadvantages and advantages of the air-lift, 346.

Artesian Wells of Australia, The, II., 312–320.
An Australian drought, 312; first artesian bore in Australia, 312; what an "artesian basin" is, 313; a vast artesian basin in Australia, 313, 314, 315; hot wells, 317; Chinese methods of well-sinking, 319; the modern system, 319, 320; facts and figures about the wells, 320; financial success of well-sinking, 320.

Asphalt deposits, Trinidad pitch lake, II., 325.

Assiout barrage, II., 399, 401–404.

Assisted shield method of tunnelling through water-logged ground, I., 306, 307.

Assouan quarries, I., 8; II., 393.

Automatic ore tips, III., 262; stokers, 230.

B

BAALBEC, great stones of, I., 10, 11.

Baikal, Lake, III., 89.

Baikal, train ferry, I., 65–79; III., 90; *see* "Building of the Train-Ferry *Baikal*."

Baker, Sir Benjamin, designer of the Forth Bridge, I., 322; evolves scheme for raising Assouan dam, II., 407.

Balayeur, the, I., 247.

Balloons, dirigible, III., 45–63; *see* "Aeronautics," Dirigible Balloons.

Barbettes, I., 401.

Barking outfall works, III., 215.

Barlow, P. W., projector of "omnibus" tunnels, I., 227.

Barmen-Elberfeld Railway, The, II., 125–128.
Locality of the railway, 125; the track, 125; track girders, 126; how the carriages are supported, 126; electric current supply to motors, 127; rolling stock, 127; cost of construction, 127; curves, speed, and traffic, 128.

Bartholdi, Auguste, designer of the statue of Liberty, III., 250, 252.

Barton swing aqueduct over the Manchester Ship Canal, I., 166.

Bateman, J. F. Latrobe, III., 189.

Battleships, I., 385–390; *see* "Armament of a Battleship," "Armour of a Battleship," "How a Battleship is fought."

Bazalgette, Sir Joseph, draws up plans for draining London, III., 211, 212.

Beam, continuous, I., 103.

Bears in railway camp, I., 26, 27.

Bedplates of Forth Bridge towers, I., 329, 330.

Beirut, I., 341.

Bell Rock lighthouse, I., 372, 373.

Bending moment of a beam, I., 103.

Bergen-Kristiania Railway, The Construction of the, III., 347–356.
The route of the railway, 347; its elevation compared with that of other railways, 348; early history, 348; mountain section surveyed, 349; building transport roads, 351; roads completed, 351; materials for track brought into mountains, 351; climatic obstacles, 352; winter work in the tunnels, 352; clearing away the snow, 353; high wages and isolation, 353; the Gravehals tunnel, 355; Italian miners imported, 355; hard times at Myrdal, 355; snow blockades, 355; tunnel completed, 355; snow-ploughs and snow-screens, 356; a railway for tourists, 356.

Bessemer process of steel making, III., 264.

Bishop Rock lighthouses, I., 377–384.

Blanchard, C. J., on "Irrigation in the United States," II., 81–102.

Blast furnace, as gas producer, I., 219; its principle, III., 261.

Blast furnace gas, used to heat stoves and raise steam, I., 219; first use for gas engines, 219; methods of cleaning, 220, 221; vast power available from, 224; diagram showing blast furnace and gas engine in series, 225.

Blasting, cliffs at Fishguard Bay, I., 174, 175, 176; rock on Canadian Pacific Railway, I., 275; snow on Bergen-Kristiania Railway, III., 352; wreck in Suez Canal, I., 252.

Bleichert, Adolph, and Co., I., 121.

Blériot, Louis, III., 11; his monoplane, III., 25.

"Block coefficient," in shipbuilding, I., 352.

Block system, for working Suez Canal, I., 253; *see* "Signalling, Railway."

"Blow-outs" from subaqueous tunnel works, I., 308; II., 120.

Boilers: Babcock and Wilcox, II., 32; *Baikal's*, I., 77; Belleville, II., 32; locomotive, *see* "Locomotives of To-day;" *Mauretania's*, II., 39;

Scotch marine, II., 31; water tube, II., 32; Yarrow, II., 32.
Booth, W. H., on "The Development of the Gas Engine," I., 215; on "Artesian Wells, and How they are Bored," III., 335.
Bouch, Sir Thomas, designer of a Forth Bridge, I., 322.
Brakes, railway, II., 246–251; *see* "Railway Brakes;" Fell system of, III., 302.
Brandt rock boring drill, III., 153.
BREAKWATERS (*see* "Harbour Construction"):
Aberdeen, III., 76; Alderney, III., 73; Algiers, III., 74; Cherbourg, III., 70; Dover, III., 78, 79; Fishguard Harbour, I., 176; Gibraltar, III., 75; Holyhead, III., 73; La Guaira, III., 76; Marseilles, II., 176, 177; Plymouth, III., 70–72; Portland, III., 74; Port Said, I., 245; Vera Cruz, III., 76; Zeebrugge, III., 75.
Brennan Louis, his torpedo, I., 438.
Brett, John Watkins, a founder of the Atlantic Telegraph Company, II., 280; director of Atlantic Telegraph Company, 282; death, 374.
BRIDGES:
Bridge, The Development of the, I., 102–107.
Carrying power of a beam, 103; application of load, 103; support of a beam, 103; continuous girder, 103; shearing stress, 104; plate girders, 104; parabolic or bowstring girders, 104; trusses, 105; "king" and "queen" trusses, 105; Warren truss, 105; lattice girder, 105; suspension bridges, 106; cantilever bridges, 106; bridge abutments and piers, 107.
Bridges, Bascule, II., 46; Blackwell's Island cantilever, II., 270–272; Britannia tubular, I., 147–152; Brooklyn suspension, II., 257, 259, 260, 261; Canadian Pacific Railway, I., 279; Clifton suspension, I., 288; Croton aqueduct, II., 273; Forth, I., 321–337, *see* "Forth Bridge, the Story of the;" Grand Trunk Railway arch, III., 278–282; Hell Gate arch, New York, II., 274; Henry Hudson memorial arch, II., 274, 275; Irtysh, III., 87; Kafué, II., 160; Manhattan suspension, II., 266–270; Manhattan Valley, II., 274; Menai Straits suspension, Telford's, I., 142–146; Niagara Falls, III., 278–287, *see* "Arch Bridges of Niagara Falls;" Oxus, II., 379; Roman, I., 18, 19; Royal Albert, Saltash, I., 34–40, *see* "Royal Albert Bridge at Saltash;" St. Lawrence tubular, I., 205–214, *see* "Victoria Bridge, the Great;" St. Louis, II., 163–171, *see* "St. Louis Bridge;" Salisbury, II., 53; Scherzer rolling lift, II., 44–49, *see* "Scherzer;" Sittang, II., 433–437, *see* "Bridge Building Feat, an Interesting;" swing, II., 44; Switchback Canyon cantilever, I., 33; Tower, II., 46; transporter, I., 287–299, *see* "Transporter Bridges;" Victoria tubular, I., 205–214, *see* "Victoria Bridge, the Great;" Walnut Lane, Philadelphia, II., 275; Williamsburgh, II., 261–266; Yenesei, III., 85; Zambesi, I., 90–101, *see* "Zambesi Bridge, the Great."
Bridge Building Feat, an Interesting: the Sittang Bridge, Burma, II., 433–437.
The river Sittang, 433; native workmen, 434; first season's work on the bridge, 434; difficulty with centre spans, 434; a novel scheme for floating them into position, 434, 435; the "Dreadnought" pontoon, 435; a tremendous storm, 435; floating first span, 436; last span floated, bridge completed and opened, 436, 437.
Bridges of New York City, The, II., 257–276.
New York a city of great bridges, 257, 258; need for these bridges explained, 258, 259, 260; ferry service, 259; traffic figures for all means of transport across river, 259. BROOKLYN BRIDGE: John A. Roebling offers to build it, 260; notable features of the Brooklyn Bridge, 260; strengthening the bridge, 261. WILLIAMSBURGH BRIDGE: main points of interest, 262; construction work, sinking pneumatic caissons for pier foundations, 263; piers and towers, 263, 264; anchorages, 264; shore spans erected, 264; spinning the cables, 264, 265; wrapping the cables, 265, 266; building the stiffening trusses, 266; an accident, 266. MANHATTAN BRIDGE: characteristics and dimensions, 266, 267; footbridges for the cable work, 267; cable-spinning apparatus, 268; cable-spinning described at length, 268, 269, 270. BLACKWELL'S ISLAND OR QUEENSBORO BRIDGE: dimensions, 271; design, 272; "travellers," 272. OTHER LARGE BRIDGES: High Bridge, 273; Washington Bridge, 273; Manhattan Valley, 274; three proposed monster bridges, 274, 275, 276.
Bridges of the Menai Straits, The, I., 142–152.
Travelling to the west coast in the eighteenth century, 142; Telford makes the great road to Holyhead, 142; decides to bridge the Menai Straits, 142. THE MENAI SUSPENSION BRIDGE: plans drawn up and approved, 143; building the piers, 143; anchoring the suspension chains, 143; hoisting chains into position, 144; joining up, 144; a workman's foolhardy feat, 145; bridge opened, 145; facts and figures, 145; the Conway Bridge, 147. THE BRITANNIA BRIDGE: the Chester-Holyhead railway, 147; railway bridge required for the Menai Straits, 147; arch bridge planned by Robert Stephenson, but disallowed by Admiralty, 147; plans for a tubular bridge, 147, 148; its chief features, 148; the huge tubes, 148; work of erection begun, 149; the towers, 149; riveters and rivets, 149; preparations for floating the first tube, 149; hydraulic presses employed, 150; first tube floated, 150; a mishap and a rescue, 150; raising the tube, 151; a serious disaster averted by precautions, 151; all tubes in position, 152; testing the bridge, 152; an appreciation of the work, 152.
Bridgewater canal, the, I., 156.
Bright, Charles, on "Early Atlantic Cables," II., 277–294, 355–374; on "The Construction and Laying of Submarine Cables, III., 357–376.
Bright, Edward, II., 277.
Bright, Sir Charles Tilston, engineer of the Magnetic Company, II., 277; makes agreement with Brett and Field to form the Atlantic Telegraph Company, 280; engineer-in-chief of the Atlantic Telegraph Company, 282; champions large conductor for first Atlantic cable, 283; desires to lay cable from mid-ocean both ways, 287; adopts Appold brake for cable work, 291; his paying-out gear, 291, 292; starts with second expedition in charge of *Agamemnon*, 356; at landing of first Atlantic cable, 360; his work appreciated in the *Times*, 361; receives honour of knighthood, 363; appreciation by Lord Kelvin, 364; reports on failure of cable, 364; recommends type for 1865 cable, 365; prevented from assisting with 1866 cable, 369; localizes faults in 1865 and 1866 cables, 374.
Brindley, James, I., 156; his demonstration of the use of clay for canals, 157.
Britannia, the, I., 315.
Broken Hill, II., 159.
Brooke "sounder," II., 278, 279.
Brunel, Isambard Kingdom (Brunel the Younger), assists his father in Thames Tunnel works, I., 188; rescues miners, 189; nearly drowned, 189; designer and engineer of the Royal Albert Bridge, 34; scheme for a harbour at Fishguard Bay, I., 173; originator of the broad gauge of the Great Western Railway, 109; designer of *Great Britain* and *Great Eastern*, 316; death, 40.
Brunel, Marc Isambard (Brunel the Elder), I., 181; early history, 182; appointed engineer of the Thames Tunnel Company, 183; resigns the office, 190; knighted, 191; stricken with paralysis, 192; first engineer to use a movable tunnelling shield, 227.
Buck, L. L., engineer-in-chief of the Niagara arch bridges, III., 279, 283.
Buckle, A. Stewart, on "An Interesting Bridge-Building Feat," II., 433.
Building of the Train-Ferry "Baikal," The, I., 65–78.
A short description of the vessel, 65, 66; accommodation for trains, 67; accommodation for passengers, 67; engines and propellers, 67; vessel built at Newcastle and taken to pieces, 68; parts shipped to Russia, 68; official blundering, 68; difficulties of transport, 68, 69; the Angara River, strong rapids, 69, 70; the shipyard on Lake Baikal, 71; keel laid, 71; intense cold of Siberian winter, 72; labour troubles, 72; framing the vessel, 73; plating, 73; shell completed, 73; building the launching ways, 74; "freezing out" process, 74; the launching ways give trouble, 76; the launch, 76; the Baikal natives, 76; putting

boilers aboard, 77; trial runs, 78; the *Angara*, 78.
Building the Statue of Liberty, III., 250–256.
Inception of the scheme, 250; the statue a gift from France to the United States, 250; principal dimensions of the statue, 251; how the model was prepared, 252; moulding the pieces, 252; the copper shell, 253; internal stiffening bars, 253; the supporting framework, 253; foundations for pedestal, 255; the pedestal, 256; erecting the statue, 255; weight, cost, etc., of statue, 256; inauguration ceremony, 256.
Buoys for submarine cables, III., 369, 371.
Burgoyne, Alan H., on "The Armour of a Battleship," I., 397; on "The Armament of a Battleship," I., 404; on "The Development of Torpedo Craft," I., 418; on "Submarine Boats," I., 427; on "Torpedoes," I., 433; on "How a Battleship is Fought," I., 442; on "The Warship of the Future," I., 453.
Burne, E. Lancaster, on "The Development of the Bridge," I., 102; on "The Electric Power-Stations of London," III., 226.
Bythell, John Kenworthy, I., 158.

C

CABLES, SUBMARINE (*see* "Early Atlantic Cables"):
Cables, Submarine, The Construction and Laying of, III., 357–376.
CONSTRUCTION (*see* II., 283, 285, 365, 366, 369): conductors, 357; insulation of conductors, 358; gutta-percha covering machine, 358; mechanical protection, 359; armour, 359; manufacture, 359; rate of, 360; jointing and splicing, 360; testing, 360; types—"shore end," 360; "intermediate," 360; "deep-sea" main, 361. CABLE LAYING: survey, preliminary submarine, 361; telegraph ships—*Colonia*, 362; *Silvertown*, 362; *Faraday*, 365; *Iris*, 365; *Telconia*, 365; shipment of cable, 365; stowage of cable aboard ship, 365; paying-out gear, 366 (*see* II., 285, 292, 294, 369); dynamometer gear, 367; holding-back gear, 368; picking-up gear, 368 (*see* II, 369); buoys and buoying, 369; programme for laying, 370; testing hut, 370; landing shore end, 371; splicing on main cable, 371; laying main cable, 373; attaching main cable to farther buoyed end, 374; testing of the cable, 375. CONCLUSION: world's cable system, 375; statistics, 375; wireless telegraphy, 375.
Cables, suspension bridge: Brooklyn Bridge, II., 260, 261; Manhattan Bridge, II., 267–270; Transporter Bridge, I., 291, 294, 298, 299; Williamsburgh Bridge, II., 262, 264–266.
Cableways, various systems of, I., 128; Famatina cableway, *see* "Ropeway in the Andes, a Wonderful Aerial."
Caissons, City Investing Building foundation, II., 5; floating, to close lock entrances, II., 186; Forth Bridge pier foundations, pneumatic, I., 325–328; Kafué Bridge piers, II., 160; Rotherhithe Tunnel shaft, pneumatic, I., 54–56; St. Louis Bridge pier, pneumatic, II., 167, 169; Thames Tunnel shaft, open brick, I., 183; Victoria Bridge, open timber, I., 207.
"Camels" for raising sunken vessels, I., 43.
Camp, railroad, life in, I., 260, 265, 273.
Canadian Pacific Railway, The Construction of the, I., 257–286.
Origin of the C.P.R., 257; constructional difficulties to be faced, 257; political difficulties, 258; public tenders called for, contract granted to a syndicate, 258; terms of contract, 258; surveys begun, 258; Sandford Fleming crosses the Rockies and selects route, 259; a fresh start made, 260. LAKE SUPERIOR SECTION, 260; gauge and weight of rails for C.P.R., 260; camp regulations, 260; heavy rock work round Lake Superior, 261; filling in swamps, 261; high bridges, 261. THE PRAIRIE SECTION: cuttings to be avoided, 263; staff organization, 263; subdivision of work, 263, 264; marking out the route, 263; forming the dump, 264; troublesome "muskegs," 264; protection against snow in prairies, 265; camp life, 265; mortality among horses, 266; movable hotels, 266; laying the track, 267; station building, 267; work done fast but thoroughly, 268. THE MOUNTAIN SECTIONS: in the Rockies, 270; Chinese labour, 270; labour problems, 270; prospecting a route in the mountains, 270; Rogers discovers Rogers Pass, 271, 272; railroading in the mountains, 273; terrific obstacles, 273; a mountain construction camp, 273; trials of the navvy, 274; blasting rock, 274; accidents, 274, 275; a comic escape, 275; winter work, 275; tunnelling, 275; the "Great Divide," 276; heavy gradients, 277; stiff climb near Hector, 277; safety switches, 278; fresh location of track near Hector, 278; bridge work, 279; pile driving, 279; Stoney Creek bridge, 280; cold and dangerous work, 280; snow-sheds, 280, 281; the "Loops," 281; the rails meet, a dramatic scene, last spike driven, 283; what the C.P.R. has done for Canada, 284, 285; great hotels of the C.P.R., Empress Hotel, Victoria, 285.
CANALS:
TRANSPORTATION: Albemarle and Chesapeake, III., 175; Bridgewater, I., 156; Chicago drainage, III., 172, 173; Florida (proposed), III., 175; Illinois and Michigan, III., 174; Lake Borgne, III., 174; Lynn, I., 23; Manchester Ship, I., 153–171, *see* "Manchester Ship Canal;" New Erie, III., 168, 169; Nile to Red Sea, I., 14; Old Erie, III., 163, 165, 167; Panama, II., 129–149, *see* "Panama Canal;" Pennsylvania, III., 175; Sault Ste. Marie, III., 170, 171; Suez, I., 241–256, *see* "Suez Canal;" United States, *see* "Transportation Canals of the United States." IRRIGATION: Ibrahimiyeh, Egypt, II., 399; Indian—Bari Doab, III., 240, 241; Chenab, III., 234–237, 239; Ganges, III., 241, 242; United States, II., 87.
Canals *v.* railways, III., 164.
Cantilever, meaning of word, I., 322; bridges, I., 106; of Forth Bridge, I., 323, 334, 335.
Cape to Cairo Railway, The, II., 150–162.
Cecil Rhodes's project, 150; road built in sections from Vryburg northwards, 151; Bulawayo reached, 152; negotiation with the Government for assistance, 152; unsuccessful negotiations with the German Emperor, 152; progress of the line, new route chosen north of Bulawayo, 153; the Zambesi bridged, 154; transport of material, 154, 155; an anecdote about Sir William Harcourt, 156; stirring incidents, 156; encounters with lions, 156, 157; the native attitude, 157; the labour question, 158; traffic returns, 158; extension to Broken Hill, 159; Kafué Bridge, 160; future developments, 160; a Belgian line into the Congo Free State, 161; another line to Lake Tanganyika, 161; German projects, 161; table of distances, 162.
Capitol at Washington, I., 9.
Capped shells, I., 402.
Car of transporter bridges, I., 289, 291, 297, 299.
Carey Act, promoting irrigation in the United States, II., 92.
Carnac, monuments at, I., 6, 7, 8.
Catskill Mountains, III., 103.
Chagres River, II., 139.
Chanute, Octave, III., 21.
Charlotte Dundas, the, I., 314.
Chat Moss, The Conquest of, I., 368, 369.
Chatham, the, in Suez Canal, I., 252.
Cherbourg Digue, III., 70.
Chicago underground freight subways, I., 359–367, *see* "Underground Freight Subways of Chicago."
Chinese labour on Canadian Pacific Railway, I., 270; methods of well-sinking, II., 319.
Churches, underpinning — Winchester Cathedral, III., 312; Holy Trinity, Hull, 315; St. Mary Woolnoth, 317.
Clément-Bayard airship, III., 58, 59.
Cleopatra's Needle, The Story of, II., 22–28.
Needle quarried at Assouan and taken to Heliopolis, 22; removed by Augustus to Alexandria, 23; acquired for Great Britain by Sir Ralph Abercromby, 23; plans for transportation, 24; obelisk encased in iron cylinder, 25; difficulties in launching, 25; the *Cleopatra* breached and repaired, 26; voyage to England commences, 26; *Cleopatra* cast adrift in a storm, 27; lost, found, and brought into the Thames, 27; re-erection of the needle on the Thames Embankment, 28; list of objects placed inside pedestal, 28; other transportation feats of a similar nature, 28.
Clerk, Dugald, invents double-acting gas engine, I., 217.
Clermont, the, I., 314.
Cleveland Bridge Company, I., 95.
Clifton Suspension Bridge, I., 288.

Coal tip at Partington coal basin, I., 168.
Cochrane, Sir Thomas, patentee of tunnelling with the aid of compressed air, I., 303.
Cody biplane, III., 24.
Coefficient, propulsive, in ship design, I., 356.
Cold, effect of on iron and steel, I., 72.
Colorado River Closure, The, III., 113–121.
The Colorado River, 113; California Development Company formed to use its waters for irrigation, 113; an irrigation canal made, 113; a serious mishap, river bursts its banks, 115; first attempt to close breach with piles and sandbags, 115; second attempt, 116; third attempt, 117; fourth attempt, engineers try to divert water, 117; fifth attempt, a large dam commenced, 119; water breaks through, 119; sixth attempt, a failure, 119, 120; seventh attempt, success at last, 121.
Colossal Tool, A, II., 382–384.
Colossi, Egyptian, I., 8.
Columbus's flagship, the *Santa Maria*, I., 313.
Comet, the, I., 314.
Composite iron and wood ships, I., 316.
Compressed air for tunnelling, I., 57, *see* "Tunnelling."
Construction of the First American Transcontinental Railroad, The, III., 129–147.
Early difficulty of crossing the continent, 129; Asa Whitney suggests a railway, 129; gold discovered in California, 130; Panama railroad built, 130; United States Government has surveys made for railroad, 131; hostility of the Indians, 131; Omaha to be the western starting-point, 131; Central Pacific Company formed, 131; Congress subsidizes Union Pacific and Central Pacific Companies, 131; a start made, but funds exhausted, 132; the second charter, 132. The UNION PACIFIC begun at Omaha, 133; crosses the prairies, 133; reaches the Rockies, 133; General Dodge discovers Sherman Pass, 133, 135; tunnelling in the mountains, 135; high cost of materials, 135; Indian hostilities, 135. CENTRAL PACIFIC starts from Sacramento, 136; climbs the Sierra Nevada, 136; passes through the snow belt, 136; high elevations on the line, 137; descends into Great Desert, and approaches Salt Lake City, 137; anxiety of Mormons lest railway should pass them by, 138; their disappointment, 138; the grades of the two railroads meet and overlap 200 miles, 138; LAST SPIKE driven at Promontory, May 10, 1869, 139; cost and quality of the line, 139; criticisms of the Central Pacific track, 140; engineering handicaps, 141; IMPROVEMENT of the Union Pacific track, 141; the Omaha cut-off, 142; the Lucin cut-off across Salt Lake, 143; driving piles in lake bottom for trestles, 144; serious difficulties encountered, 145; recent history of the track, 145; what the Overland Route has done, 145; conclusion, 147.
Construction, railway, I., 346.
Continuous beam in bridge construction, I., 103.
Conversion of the Gauge of the Great Western Railway, The, I., 108–118.
The broad gauge, 109; its disadvantages, 109; growth of the narrow gauge throughout the country, 109; need for narrowing the broad gauge, 109; the work to be done, 110; clearing the line, 110; the last day of using the broad gauge, 111; signal to commence work, 111; last "up" broad gauge train, 111; instructions to stationmasters, 112; "death warrants" issued, 112; labour organization, 113, 114; lodging the men, 113; altering the gauge, 114; methodical work, 114; difficulties on curves, 115; cutting rails, 115; testing the line, 116; gauge converted in thirty hours, 116; cost of alteration, 117; narrow gauge unalterable, 118.
Conveyor at Victoria Falls Bridge, I., 96.
Cooling pistons by circulation of water, I., 225.
"Cornishman," the, I., 111.
Corrosion of steel, prevented by concrete casing, II., 13.
Corruption of Russian railway officials, III., 84, 88.
Cost of railway construction, Hedjaz Railway, I., 348.
Cotton crop in Egypt, II., 390, 407.
Cradles for ship launching, II., 76.
"Cradling" of bridge cables, I., 299.
CRANES:
Goliath, III., 69, 79, 271; "Jubilee," at Forth Bridge, I., 334; ladle, in steel works, III., 267; locomotive, II., 223; shipbuilding yard, II., 66, 67; Titan, III., 69; travelling, at Victoria Bridge, I., 209.
Cruisers, armoured, I., 391; protected, 391.
Crystal Palace, first iron frame cage building, II., 3.
Culebra cutting on Panama Canal, II., 135, 145, 148.
Curtain walls, II., 2.
Curves—Chicago freight subways, I., 367; Fell railway, III., 304.
Cut-and-cover work—aqueduct, III., 179; New York subway, II., 345–347; Rotherhithe Tunnel, I., 52.

D

DALRYMPLE HAY, Harley H., on "The Tube Railways of London," I., 227–240, 300–311.
DAMS (*see* "Great British Dams and Aqueducts," "Nile Dams and Assouan Reservoir," "Water Supply of New York City"):
Assouan, II., 391–398; Bhatghur, III., 245; Blackwater, III., 274; Caban Coch, III., 189; Colorado River, *see* "Colorado River Closure;" Craig Goch, III., 190; Cross River, III., 102; Derwent, III., 191; Ganges Canal, III., 241; Gatun, II., 140; Howden, III., 191; Loch Katrine, III., 179; Loch Vennachar, III., 179; Marikanave, III., 246; Needle, III., 176; New Croton, III., 101; Nidd, III., 192; Old Croton, III., 98; Olive Bridge, III., 105–107; Pen-y-gareg, III., 190; Periyar, III., 245; Roosevelt, II., 99; Shoshone, II., 101; Thirlmere, III., 183; Vyrnwy, III., 180; Yuma, II., 101.
Deacon, G. F., engineer of Vyrnwy-Liverpool aqueduct, III., 180.
"Dead Horse Trail," I., 25.
Delta barrage, II., 389, 390.
Deltas, formation of, III., 242; Godaveri, III., 244.
Desert, Great, of United States, II., 90.
Designing a Ship, I., 350–358.
Factors of design, 350; choice of dimensions, 351; form of the ship, 352; distribution of weight in various kinds of vessels, 352; "gross and net tonnage" explained, 352; metacentric height and its effect on stability, 353; strength increased by employment of steel, 353; longitudinal strength, 353, 354; varieties of structural design, 354; general arrangement of steamship, 355; water ballast, double bottoms, 355, 356; cabin accommodation, 356; speed, resistance, and propulsion, 356; experimental tanks, 356; "propulsive coefficient," "indicated horse-power," "slip," 356, 357; rolling in a seaway, 357; the Schlick gyroscopic principle of preventing rolling, 358.
Destroyers, I., 395; trials, 395, 396; ocean-going, 419; development of, 421; high speed, 421, 422; on a destroyer, 424.
Development of the Ship, The, I., 312–320.
Birth of the shipbuilding industry, 312; Egyptian galleys, 312; Alfred the Great the founder of the British navy, 313; Viking ships, 313; Columbus's flagship, the *Santa Maria*, 313, 314; application of STEAM to marine propulsion, 314; the *Charlotte Dundas*, *Clermont*, and *Comet*, 314; early Atlantic steamships, the *Savannah*, 315; decline of the sailing ship, 315; wood, composite, and iron ships, 316; the *Great Britain* screw steamship, 316; the *Great Eastern*, 316, 317, 318; developments during the past fifty years, 318, 319; increase in size and speed, 319; will steamships continue to grow in size and speed? 319, 320.
Development of the Racing Motor Car, The, III., 321–334.
Racing cars very wonderful machines, 321; what is required of them, 321; the first important race, Paris to Rouen, 322; twenty-one cars take part, 323; a humorous incident, 323; Paris-Bordeaux race of 1895, 324; the winning car, 324; Paris-Marseilles-Paris race of 1896, 324; Paris-Amsterdam-Paris race of 1898, 325; tour de France, 1899, 325; an average speed of 27 miles an hour, 325; first Gordon-Bennett race, 1900, a partial fiasco, 325; weight limitations in the 1902 Gordon-Bennett race, Paris to Vienna, 326; Paris-Madrid race, 1903, 326; tyres and speed, 327; racing in Ireland for Gordon-Bennett cup, 1903, 327; Théry wins 1904 Gordon-Bennett race for France, 328; prac-

tical results of racing, 328; the last Gordon-Bennett race, 1905, Théry wins again, 329; detachable rims used by competitors for Grand Prix in 1906, 330; fuel limitations for 1907 Grand Prix, 330; cylinder bore limited for 1908 Grand Prix, 331; restrictions abandoned for 1910, 332; track racing, 332; record-breaking "freak" cars, 333; table of speed records, 334.
"Devil's Belly," the, on Hedjaz railway, I., 344.
Dhu Heartach lighthouse, I., 374.
Distillation of petroleum, II., 336.
Distribution of electrical energy in London, three-wire system, III., 226.
Diver employed for underpinning work at Winchester Cathedral, III., 313, 314; in Severn Tunnel, I., 83, 84.
Diver's dress, III., 314.
Dixon, John, engineer who transported Cleopatra's Needle from Egypt to England, II., 24.
DOCKS:
Dry, II., 179.
Floating, *see* "Docks, Floating;" Govan, II., 179; Liverpool, II., 176; Manchester, I., 167; Tilbury, II., 177; timber, II., 185.
Docks, II., 173–187.
Definitions of dry docks, wet docks, etc., 173, 174; sites for docks, various considerations, 174; arrangement of a port, 175; jetties, 175; need for suitable approaches, 176; breakwaters, training walls, etc., 177. WET DOCKS, 177; half-tide basins, their use, 177; lock entrances, 177; locks, 178; how constructed, 178, 184, 185. DRY DOCKING a ship, 178; large dry docks, 179; construction of docks, 181, 182; foundations for dock walls, 183; monolith foundations, 183; rear support of a wall, 184. DOCK GATES, 185; straight, curved, and segmental gates, 185; caisson types of gate, 186, 187.
Docks, Floating, II., 409–417.
Origin of the floating dock, 409; the first floating dock, 409; great increase in popularity of the floating dock, 410; low cost and rapid construction, 410; method of working a floating dock, 411; the "box" dock, 411; depositing docks, 412; off-shore docks, 412; sectional pontoon and Havana types, 413; bolted sectional type, 416; Bermuda dock, 413, 415, 416; Philippine dock, 416; remarkable voyages of floating docks, 417.
Docks determine size of ships, I., 320.
Dog-shores, II., 77.
Dolmens, I., 7.
Double bottom of ships, II., 70.
Douglass, N., I., 378, 379.
Douglass, Sir J. N., I., 375, 380.
Douglass, W. T., I., 379, 380, 384.
Douie, Andrew, on "The Building of the Train Ferry *Baikal*," I., 65–78.
Dragonfly, the, II., 43.
Drags for ship launching, II., 77.
Drainage—of London, *see* "Wonderful Drainage System of London;" of swamps by ploughing, III., 292; of tube railway tunnels, I., 309.
Dreadnought, H.M.S., I., 319; armour, 390; cost, 390; guns, 388.
Dredgers or dredges—hydraulic, III., 169, 173; rock breaking, I., 251; Suez Canal, I., 246, 251.
"Drift" of a kite, III., 5.
Drilling artesian wells, III., 337; oil wells, II., 327.
Drills—Brandt hydraulic, III., 153; Ferroux air, 152; Siemens and Halske electric, 307; Sommeiller air, 152; well-sinking—calyx, 338; chisel, 338; diamond, 338; shot, 339.
Driving last spike—Canadian Pacific Railway, I., 282; Union Pacific Railway, III., 139.
Drought in Australia, II., 312.
Duluth transporter bridge, I., 292.
Dumont, Santos, III., 1; wins Deutsch Prize, 51.
"Dumpling" of earth in cut-and-cover tunnelling, I., 52.
Dupuy de Lôme's dirigible balloon, III., 51.
Dynamometer Car, a Railway, II., 253–255.

E

Early Atlantic Cables, II., 277–294, 355–374.
THE PIONEER LINE: the Magnetic Telegraph Company champions a scheme for laying an Atlantic cable, 277; Gisborne's concession, 277; Gisborne sells to a syndicate, 278; cable laid from Newfoundland to Cape Breton, 278; exploring the bed of the Atlantic, 278; the Brooke sounder, 278; a submarine plateau discovered, 279; Field approaches Magnetic Telegraph Company, 279; agreement signed to form a company for laying an Atlantic cable, 280; prejudice and criticism aroused by the scheme, 280; Government recognition, 281; Atlantic Telegraph Company registered, 281; most of the capital raised in the United Kingdom, 282; fallacies and curious suggestions by the inexpert, 282; manufacture of the cable, 283, 285; ships and paying-out machinery, 285; preparations for the start, 286; the first start, 287; anxious work, 288; the cable snaps, 289; preparations for another attempt, 289; necessary funds raised, 291; new paying-out gear constructed, 291; principle of Bright's paying-out gear explained, 291, 292; Thomson's reflecting galvanometer, 293, 294; rehearsal for second attempt, 294. SECOND EXPEDITION: a start made, 355; tempestuous weather, 355, 356; repeated troubles, 356; ships return home, 357; projectors determine to persevere, 357; another start made, 357; exciting incidents, 357; great anxiety aboard ship, 358; both ships reach land, 360; first transatlantic message sent, 360; general congratulations, 361; American enthusiasm, 362; curious coincidences, 362; working the line, a famous message sent, 363; the cable fails, great public disappointment, 363, 364; the inquest, cause of failure determined, 364. THE 1865 CABLE: cost of cable subscribed in Great Britain, 365; the new cable, 365, 366; *Great Eastern* secured for laying it, 366; laying operations started, 366; faults discovered, 368; the expedition fails, 368. THE 1866 CABLE: Anglo-American Telegraph Company formed, 368; new main cable similar to its predecessor, new shore-end type, 369; improvements in paying-out and picking-up machinery, 369; *Great Eastern* sets out again, 369; a foul in the cable tank, 370; the cable landed, 370. THE 1865 CABLE (*continued*): repeated failures in attempts to bring it to surface, 371; brought up at last, 372; cable completed, 372; conclusion, 372.
Earthquakes, their effect on steel buildings, II., 10, 11.
Egyptian ships, I., 312.
Eiffel, M., designer of frame for statue of Liberty, III., 253.
Ejector, mud, I., 327.
El Ula, on Hedjaz Railway, I., 345.
Electric furnaces for separation of aluminium, III., 273.
Electric Power-Stations of London, The, III., 226–231.
Some figures, 226; uses of electricity, 226; systems of distribution, 226; the three-wire system explained, 227; alternating current, 227; transformers, 227; future supply, 229; alternating and direct current both needed, 229. LOT'S ROAD POWER-STATION, 230, 231: coaling facilities, 230; automatic stokers, 230; boilers, generators, and steam turbines, 231.
Embankments—Manchester Ship Canal, I., 159–162; Omaha cut-off, III., 142; New Chingford reservoir, III., 199.
Engineering, ancient, I., 5–20.
Engines, aeronautical, III., 29–37, *see* "Aeronautical Engines;" pumping, *see* "Pumping Engines."
Electric towage on canals, III., 167.
Elevator, high speed, II., 20.
Equipment of a Modern Shipyard, The, II., 65–80.
Economy of vital importance, 65; building berths, 65; berths at Newport News, 65; covered berths, 66; cableways for handling materials, 66; gantries at Belfast, 66, 67; shipyard machinery, 67. BUILDING A SHIP: the working model, 68; "laying off" in the mould loft, 68; the frames scrived, 70; laying the keel, 70; keel blocks arranged on gradient, 70; keel, keelson, and double bottom, 70; framing a vessel, 71; beams and bulkheads, 72; stern bar and stern frame, 73; plating and riveting, 74; caulking and painting, 75. LAUNCHING A SHIP: an anxious process, 75; the ground-ways, 75; sliding ways and cradles, 76; transferring ship's weight to the ways, 76; the "dog-shores," 77; the drags, 77; launching the *Mauretania*, 78. COMPLETION: shipping the machinery, 79; fitting-out, 79, 80; the trial trip, 80.
Ermack, lengthening of the, III., 122.
Escape from drowning, wonderful, II., 120.
Esneh barrage, II., 404, 405.
Everglades of Florida, the, I., 129, 130.
Exactitude in calculation of bridge mem-

bers, etc., III., 285; in manufacture of tubes for Victoria Bridge, I., 210; in tunnelling, II., 116; III., 149 (Mont Cenis Tunnel); III., 155, 156 (Simplon Tunnel).
Excavating machinery for Chicago Drainage Canal, III., 173; New Erie Canal, III., 169; Panama Canal, II., 146, *see* also "Dredgers."
Expansion of metals, provision for in Forth Bridge, I., 330, 335.
Experimental tanks for testing models of ships, I., 356.

F

FARMAN biplane, III., 23.
Fell railway, III., 301–306.
Ferry service in New York, II., 259.
Field, Cyrus West, II., 278; comes to England, 279; makes agreement with Bright and Brett to found Atlantic Telegraph Company, 280; general manager of Atlantic Telegraph Company, 282; congratulated on success of first Atlantic cable by Legislative Council of Newfoundland, 361; tries to raise funds in America for 1865 cable, 365; sails on 1866 expedition, 368.
Filter beds, III., 204.
Fires in oil-fields, II., 333, 334.
Fishguard Harbour, The Construction of, I., 172–180.
Fishguard Bay, 172; its suitability for a harbour, 173; Brunel's scheme, 173; a modern scheme by Great Western Railway Company, 175; work to be done, 175; excavating the rock, 175; great blasts, 176; the breakwater, 176; the quay wall, 176; accommodation for cattle, 178; quay equipment, 178; weather-recording instruments, 179; Fishguard liners, 179, 180.
Flagler, H. M., promoter of the Florida East Coast Extension Railway, I., 129, 139.
Flat iron building, New York, II., 1, 14.
Fleming, Sir Sandford, reports on and surveys route of Canadian Pacific Railway, I., 258, 259.
Floating first tube of the Britannia Bridge, I., 150; spans of Saltash Bridge, 37, 38.
Florida East Coast Railway Extension, The, I., 129–142.
A remarkable scheme, 129; Mr. Henry M. Flagler, 129; difficult surveying, 129, 130; construction work—dredging in the swamps, 130; grading across Key Largo, 131; labour difficulties, 131; workmen's floating hotels, 132; railway built largely from boats, 132; table of distances, 132, 133; the viaducts, 133; enormous quantities of material needed, 133; how the viaducts were built, 134; the works swept by storms, thrilling adventures, 135, 136; Knight's Key terminus, 137; dredging in the islands, 137; viaduct track 30 feet above water, 138; the engineers in command, 139; progress of the work, 139; lonely dwellers on the Keys, 140; transforming Key West, 140; cost per mile, 140; a wonderful journey, 141.
Forced draught in ship's stokehold, II., 33.
Forth Bridge, The Story of the, I., 321–337.
The Firth of Forth, 321; how people crossed it prior to the erection of the Forth Bridge, 321; barren schemes for tunnelling and bridging the firth, 322; Sir Thomas Bouch's designs for a suspension bridge, 322; bridge begun, but abandoned, 322; the final scheme of Messrs. Fowler and Baker, a cantilever bridge, 322; meaning of the word "cantilever," 322; dimensions of the Forth Bridge, 322; the cantilevers, 323; the suspended girders, 323; main spans and approaches, 323; why the present site was chosen, 323; the three towers supporting the cantilevers, 323; work commenced late in 1882, 324; careful measurements to fix exact sites of piers, 324; workshops, yards, etc., prepared on Queensferry shore, 325; the Queensferry jetty, 325; TWELVE CIRCULAR PIERS for the towers, 325; use of open and pneumatic caissons for sinking the pier foundations, 325; soundings for Inchgarvie foundations, 325; sinking Inchgarvie south caissons, 325, 326; use of compressed air, 326; the Queensferry caissons, 326; floating them into position, 327; silt removed from caisson by mud ejector, 327; hydraulic spade for cutting the clay, 327; accident to a caisson, 327; how the damage was rectified, 327; air-chambers filled with concrete, 328; the granite piers, 328; the lower bed-plates, 329; facts and figures about the foundations and piers, 329. THE SUPERSTRUCTURE: "skewbacks," 329; provision for expansion and contraction of the metal members, 330; key-plates and upper bed-plates, 330; their purpose and action explained, 330; preparing the giant tubes for towers and cantilevers, 331; erection of the steel work begun, 331; movable platforms for tower construction, 331; how the platforms were raised, 332; correcting the inclination of the columns, 332; towers completed, 332; workshops 360 feet above water, 334; "Jubilee" cranes for building out cantilevers, 334; cantilevers completed, 334; details of the extremities, 335; clever device for permitting movement of cantilevers, 335; building the central girders, 335; joining up the girder booms, 335, 336; a delicate task, 336; a dramatic episode, 336; an ingenious self-adjusting rail joint, 336; cost of the bridge, 336; a splendid success, 337.
Foundations of Holy Trinity Church, Hull, III., 315; Royal Albert Bridge, Saltash, I., 35; St. Mary Woolnoth, III., 318; steel frame buildings, II., 5; Winchester Cathedral, III., 313, 315; *see* "Bridges."
Fowler, Sir John, designer of Forth Bridge, I., 322.
Fox, C. Beresford, I., 95.
Fox, Francis, III., 313.
"Freezing out," I., 74.
"Front end" of tunnelling shield, I., 240.
Froude, W., experiments with ship models, I., 356.
Fuel, liquid, and its uses, II., 340; *see* "Oil Fuel."
Fullard, T. Fletcher, on "Russian Railways in Central Asia," II., 375; on "The Trans-Siberian Railway," III., 81.
Fulton, H. H., I., 153.
Fulton, Robert, builder of the *Clermont*, I., 314.
Furnace—blast, III., 261; chargers, mechanical, 267, 270; electric, 273; open-hearth, for steel making, 265; tilting open-hearth, 265.

G

GAIRNS, J. F., on "Locomotives of To-day," II., 193–214; on "Electric Locomotives," II., 217–222.
Gales, violent, in Cornwall, II., 441.
Gares in Suez Canal, I., 251.
Gas Engine, The Development of the, I., 215–226.
The steam engine, 215; the energy of heat, 215; the internal combustion engine, 216; early gas engines, 216; Beau de Rochas's discovery of the value of compression, 216; need for cooling the cylinder, 217; Dugald Clerk introduces double-acting engine, 217; the gas "producer," 217; chemical action in the "producer," 217; cheap gas causes boom in gas engines, 218; Thwaite's discovery regarding blast furnace gas, 219; uses it successfully in a gas engine, 219; furnace gas cleaners and scrubbers, 220, 221; Nürnberg four-stroke double-acting engines, 221; two-stroke Körting engines, 221, 223; the Oechelhauser engine, 223, 224; huge American gas engine installations, 224; wealth in blast furnace gas, 225; an interesting cycle of operations, blast furnace and gas engine, 225; thermal efficiency of various types of engine, 226.
Gas producers, I., 217; chemical action in, 217; blast furnace as gas producer, 219.
Gas, natural, in United States, II., 339; sulphuretted hydrogen, encountered in Thames Tunnel, I., 191.
Gatun lake, II., 139, 142.
Gauge, railway—broad, Great Western Railway, I., 109 (*see* "Conversion of the Gauge of the Great Western Railway"); South African railways, II., 153; Uganda railway, II., 54.
General Post Office Buildings, new, II., 430–432.
Gibbon, J. M., on "The Construction of the Canadian Pacific Railway," I., 257.
Giffard's dirigible balloon, III., 1, 49.
Girders—Saltash Bridge arched, I., 36, 39; braced, 105; continuous, 103; parabolic, 104; plate, 104; Forth Bridge suspended, I., 323, 335, 336; under St. Mary Woolnoth, III., 318, 319, 320; *see* "Bridges" (*passim*).
Gisborne, F. N., concessionaire for telegraph in Newfoundland, II., 276; sells rights to C. W. Field, 277.

Gladiator, the salving of the, I., 41–48; *see* "Salving of the *Gladiator*."
Globe and Phœnix mine, II., 153.
Gold discoveries in the Klondike, I., 21.
Gorgas, Colonel, sanitary officer at Panama Canal works, checks malaria, II., 137.
Governing Pelton water-wheels, III., 277.
Gradients on—Canadian Pacific Railway in Rockies, I., 277; Central Pacific Railway, III., 140; Famatina cableway, I., 125; Fell railway, III., 303; Hedjaz Railway, I., 345; Jungfrau railway, III., 307; Mont Cenis Tunnel, III., 151; St. Gothard, III., 152; Simplon Tunnel, III., 155; tube railways, I., 311; Uganda railway, II., 58; Wetterhorn railway, II., 191; White Pass railway, I., 32.
Grapnels for picking up submarine cables, II., 371.
Great Britain, the, I., 316.
Great British Dams and Aqueducts, III., 177–192.
Roman aqueducts followed hydraulic gradient, 177; modern aqueducts include pipe syphons, 179; three methods of construction now used—tunnelling, cut-and-cover, and syphons, 179; balancing reservoirs on pipe lines, 179. GLASGOW AQUEDUCTS, 179, 180. VYRNWY-LIVERPOOL SCHEME, 180; Vyrnwy dam, 180; inlet water tower, 181; the aqueduct, 181; Norton Tower, 181; tunnels on the aqueduct route, 182; tunnelling under the Mersey, a difficult task, 182; ingenious temporary connection across the Mersey, 183; Lake Vyrnwy, 183. THIRLMERE-MANCHESTER SCHEME, 183; the aqueduct, 183; cast-iron pipes, their size, manufacture, and jointing, 185, 186; automatic check valves, 187, 188. ELAN-BIRMINGHAM SCHEME, 189; the Elan and Claerwen water-sheds, 189; Caban Coch dam, 189; submerged dam, 190; Pen-y-gareg and Craig Goch dams, 190; submerged buildings, 190, 191; the aqueduct, 191. OTHER SCHEMES: Derwent valley waterworks and Derwent dam, 191; Bradford's supply from the river Nidd, 192.
"Great Divide," the, Canadian Pacific Railway, I., 276.
Great Eastern, the, designed by I. K. Brunel, I., 316; compared with *Lusitania*, 317, 318; used for laying 1865 and 1866 Atlantic cables, II., 366–372.
Greathead, J. H., inventor of the circular tunnelling shield, I., 228.
Great Irrigation Works of India, The, III., 232–249.
Extent of Government irrigation works, 232; their social effect, 232, 233; rainfall of India, 233; systems and location of irrigation works, 233, 234; statistics of areas, 234. CHENAB CANAL, 235; dimensions, 235; what the canal has done, 235; laying out the canal system, 236; subdividing the tract irrigated, 236; escape reservoirs for surplus water, 236; the Chenab weir, 238; weir shutters, their action, 238; cost of the scheme, 239. BARI DOAB CANAL, 240; irrigates one million acres, 240; the head-works badly placed, 241. GANGES CANAL, 241; head-works, 241; building temporary dams to divert the water from river into canal, 241; Solani aqueduct, 242. GODAVERI DELTA CANAL SYSTEM, 242; how deltas are formed, 242; the canals, 244. TANKS AND RESERVOIRS: Periyar tunnel, dam, and reservoir, 244, 245; Lake Whiting and the Bhatghur dam, 245; Lake Fife, 245; Marikanave reservoir and dam, a colossal scheme, 246. CONCLUSION: the irrigation engineer's life, 246; contrasts produced by irrigation, 246, 247; plenty and famine, 248; the distribution of food in famine areas, 248; value of irrigated crops, 249.
Great Tunnels through the Alps, The, III., 148–162.
The Alps as barriers, 148; Semmering Pass railway constructed, 149. MONT CENIS TUNNEL: financial agreement between French and Italian Governments, 149; the tunnel to be of unprecedented length, 149; tunnel completed in thirteen years of work, 149; details of the tunnel—dimensions, gradients, cost, etc., 151. ST. GOTHARD TUNNEL: a Swiss proposition supported by Italy and Germany, 151; respective contributions, 151; details of tunnel, 151; gradients, 152; work begun in September 1872, 152; improved drills and explosives, but bad ventilation, 152; tunnel completed, New Year's Day, 1882, 152. ARLBERG TUNNEL: length, gradients, etc., 152; work begun, November 1880, completed September 1884, 153; system of headings used, 153; quick progress made owing to employment of Brandt rock drill, 153; description of Brandt drill, 153; good ventilation of the workings, 154. SIMPLON TUNNEL: the Simplon Pass and Napoleon's road, 154; projects for a tunnel, 154; convention signed between construction company and Swiss and Italian Governments, 155; system of twin tunnels adopted, 155; gradients and terms of contract, 155; surveying the pass and mountains, 155; accuracy of calculations proved, 155, 156; ventilating the headings, 156; series of operations performed during every advance of the drills, 156, 157; compressed air locomotives, 157; difficulties encountered—crushing in of the timbering in Italian workings, 157; steel frames and cement lining substituted, 158; hot springs struck on the Swiss side, 158; work temporarily abandoned by Swiss party, 158; Italian party encounters hot spring, but turns its flank, 159; headings meet, 159; first train passes through, January 25, 1906, 159; a coincidence of dates, 159; second tunnel to be completed when traffic demands, 160; ventilation of the tunnel, 160; electric locomotives for hauling trains through the tunnel, 160; cost and figures of the tunnel, 160. LOETSCHBERG AND TAUERN TUNNELS, 162.
Great Underpinning Achievements, III., 312–320.
What "underpinning" is, 312. Serious subsidence of WINCHESTER CATHEDRAL, 312; cause of subsidence, 313; a diver employed for the underpinning work, 313; diver's dress, 314; what the diver had to do, 314, 315. HOLY TRINITY CHURCH, HULL: ominous cracks in the structure, 315; church tower supported originally on a timber raft, 315; condition of raft and timber piles, 316; grillage beams substituted, 316; old pier foundations removed, 316; the church saved, 316. ST. MARY WOOLNOTH: a railway station under a church, 317; history of the church, 317; decision to support it on girders, 318; supporting the column bases, 318; work under the south wall, 319; underpinning the north wall, 319; station booking-hall and lifts, 320.
Greeley, Horace, and Greeley colony, II., 86, 87.
Gross airship, III., 6.
Grotto of Posilippo, I., 19.
Grouting apparatus, I., 61, 309; used for tunnel lining, 61.
Gunboats, I., 393.
Guns, big, I., 404–417; ammunition hoists, 411; barbettes, 410; breech-blocks, 408; calibre, 404, 407; erosion, 410; firing, 410; mountings, 409, 412; muzzle energy, 409; obturator, 409; penetration, 403; recoil absorbers, 409; rifling, 408; sighting, 411; weight, 411; wire winding, 408.
"Gushers" in oil-fields, II., 329–332.
Gyroscope—in aeronautics, III., 12; Schlick, for steadying ships, I., 358; for steering torpedoes, I., 436.

H

HADJ, the, or sacred journey of the Moslems, I., 339.
Haifa, I., 341.
Half-tide basins in docks, II., 177.
Harbour Construction, III., 65–79 (*see* "Fishguard Harbour, the Construction of," I., 172–180).
Types of breakwaters, 65; two main orders of waves, 65; enormous wave-pressures, 65; methods of wave stopping, 67; remarkable instances of wave force, 67, 68, 74; preliminary investigation of harbour site, 68; value of Portland cement in harbour work, 68; "Titan" or "Goliath" cranes, their respective principles and advantages, 69. CHERBOURG DIGUE, 70. PLYMOUTH BREAKWATER, 70; begun by Rennie in 1811, 70; Rennie's method, 71; the authorities interfere, slope of faces steepened, 71, 72; Rennie's theory proved correct by a storm, 72; original slope re-adopted, 72; breakwater completed, material consumed, cost, 72. HOLYHEAD BREAKWATER, 73. ALDERNEY BREAKWATER, 73. DUBLIN HARBOUR, 73; enormous concrete blocks used, 74. WICK HARBOUR, 74; great monoliths moved by waves, 74. PORTLAND HARBOUR, 74; how the moles were formed, 74. ALGIERS HAR-

BOUR, "random" blocks used, 74. GIBRALTAR HARBOUR, island breakwater built out from an artificial island of concrete, 75. ZEEBRUGGE HARBOUR, a novel method of moving concrete blocks, 75, 76. LA GUAIRA HARBOUR, the "sack block" system, 76. VERA CRUZ HARBOUR, 76, 77. DOVER NEW ADMIRALTY HARBOUR, 78; the work done, 78; wall form of breakwater, 79; excavating the cliffs, 79; constructing gantries for Goliath cranes, 79; the cranes at work, 79; great improvement in speed, 79; tonnage of blocks used, 79.

Harcourt, Sir William, story about, II., 156.

Harland and Wolff's shipyard, Belfast, II., 66, 67.

Harriman, E. H., I., 367; III., 145.

Harvey process of armour-plate making, I., 399.

Hawkshaw, Sir John, engineer-in-chief of the Severn Tunnel, I., 81, 87, 89; reports in favour of the practicability of constructing the Suez Canal, I., 243.

"Heclon" armour-piercing shells, I., 390.

Hedjaz Railway, The, I., 339–349.
Its religious origin, 339; old methods of reaching Mecca, 339; Jeddah exposed to attack by sea, 340; Sultan proposes a railway, 340; Moslem enthusiasm, 340; Haifa-Deraa branch line, 341; Medina main line, 343; lack of water, 344; negotiating the "Devil's Belly," 344; clever engineering, 345; Tebuk station, 345; El Ula, 345; religious barrier to employment, 345; construction work, a well built railway, 346; rolling stock and locomotives, 347; the future of the railway, 349.

Heming, Arthur E., on "The Marconi Towers, Poldhu, Cornwall," II., 438.

Hennebique system of reinforced concrete, II., 423.

Hennepin, Father, discovers Niagara Falls, II., 298.

Hensman, Howard, on "The African Transcontinental Telegraph," I., 193; on "The Cape to Cairo Railway," II., 150; on "The Uganda Railway," II., 50.

Herodotus's account of building the Pyramids, I., 14.

Hertzian waves for controlling torpedoes, I., 439.

High prices for land in New York, II., 1.

Hill, G. H., engineer of the Thirlmere-Manchester aqueduct, III., 189.

Hobson, G. A., designer of Zambesi Bridge, I., 92.

Holyhead breakwater, III., 73.

Hood, Albert G., on "Designing a Ship," I., 350; on "Floating Docks," II., 409; on "Some Extraordinary Shipbuilding Feats," III., 122; on "The Development of the Ship," I., 312; on "The Equipment of a Shipyard," II., 65; on "The Propelling Machinery of a Ship," II., 29; on "Warships," I., 385.

Hooded shield and clay-pocket system of tunnelling through water-logged ground, I., 306, 307.

Horses, terrible mortality among, on White Pass trail, I., 25.

Hot artesian wells in Australia, II., 317.

Hotels of the Canadian Pacific Railway, I., 285.

How a Battleship is fought, I., 442–452.

How Buildings are transported bodily, II., 446–448.

How London gets its Water, III., 193–208.
The huge population supplied, 193; some striking figures, 194; early history of the London water supply, 194; London Bridge water works, 194; the NEW RIVER scheme 194; James I. assists Sir Hugh Myddleton, 194; New River completed, 195; James Watt's improvements of the steam engine, 195; increase in the number of water companies, 195, 196; Metropolitan Water Board formed, 196; sources of supply, 196; productive wells in Kent, 196; reservoirs, 197, 198; Staines reservoirs, 198. CHINGFORD NEW RESERVOIR, 198; its embankments, 199; excavations, 199; a wonderful steam turbine, 200. BEACHCROFT RESERVOIR, Honor Oak, 201, 203. LEE BRIDGE PUMPING STATION, 203; Cornish pumping engines, 203; filter beds, their construction, 204; a mechanical sand-washer, 204; other pumping engines, 204, 206; the big well, 206; stand pipes and air chambers on mains, 206; water turbines, 206. WALTHAMSTOW RESERVOIRS, 206; water mains, figures, 206; future extensions of supply, 208; what chalk deposits do for London, 208.

Hulett ore unloader, III., 257–259.

Hunter, W. H., I., 169.

Hurricane, effects of, II., 169.

Hydraulic bender, for ship's frames, II., 71; erector, for raising segments of iron tunnel lining, I., 300; presses, in bridge building, I., 39 (Saltash Bridge); I., 150 (Britannia Bridge); I., 331 (Forth Bridge); riveter, II., 252; spade, for clay cutting, I., 327; wheel press, II., 252.

Hydrostatic disc in torpedoes, I., 435.

I

ICEBREAKERS—*Baikal*, I., 65–78; *Ermack*, III., 122.

Ice "gorges" in Mississippi, II., 164.

Ice jam in Niagara gorge, III., 287.

Ice "shovings" on St. Lawrence, I., 206.

Imperial valley, III., 112, 113.

Inchgarvie Island, I., 323, 325.

Indian coolies on Uganda railway works, II., 55.

Indian irrigation, *see* "Great Irrigation Works of India."

Indian labourers on United States irrigation works, II., 99.

Indians, frauds practised on, I., 24; their hostility to railroad men, III., 131, 133, 135.

Ingot-extracting machines, III., 268.

Internal combustion engine—development of the, I., 215–226; for ships, II., 43.

Inventiveness stimulated by necessity, I., 209.

Invincible, *Inflexible*, and *Indomitable*, I., 391.

Iris—first British steel ship, I., 319; telegraph ship, III., 364.

Iron used in the construction of ships, I., 316.

IRRIGATION:

Irrigation basin and perennial systems, II., 387–389.

Irrigation in India, *see* "Great Irrigation Works of India."

Irrigation Work in the United States, II., 81–102.
Ancient irrigators, 81; the mission fathers, 83; first attempt at irrigation in the United States by English-speaking people, 83; rice growing, 83, 85; natural irrigation on the Mississippi, 84; Mormon irrigation work in Utah, 85; settlement of the West, 86; the Greeley colony, 87; boom in irrigation canals, 87; steady growth in irrigated area, 87. ARID REGIONS OF THE UNITED STATES: great plains, 88; Platte and Yellowstone rivers, 89; Arkansas river, 90. THE TRUE DESERT: laws recognizing irrigation—Desert Land Act, 91; Carey Act, 92; Reclamation Act, 93; vigorous measures for increase of irrigation, 93. UNCOMPAHGRE PROJECT, Colorado, 95–98; a difficult problem, 95; wonderful surveying of river Gunnison, 95; difficult levelling over the mountains, 97; subsidiary work, 98. THE GUNNISON TUNNEL, 98. SALT RIVER PROJECT, ARIZONA, 98–100; Roosevelt dam, 98; Indian labourers, 99; power-station, 100. OTHER LARGE IRRIGATION WORKS OF THE FEDERAL GOVERNMENT, 101; Yuma dam, 101; summary, 102.

Ismailia, I., 253, 255.

Isthmus of Panama, II., 129, 134, 135.

J

JACKETING cylinders of gas engines, I., 225; of steam engines, 216.

Jacobs, Charles M., II., 110.

James I. and the New River, III., 194.

Jordan, railway bridge over the, I., 341.

"June Bug" aeroplane, III., 11.

Jungfrau railway, III., 306–311.

K

KAFUÉ BRIDGE, II., 160.

Key-plates of Forth Bridge towers, I., 330, 331.

Key West, I., 129, 140.

Kicking Horse Pass, I., 272; highest point reached by Canadian Pacific Railway, 276.

Kingston-Holyhead liners, I., 319.

Kinlochleven Works of the British Aluminium Company, The, III., 272–277.
Aluminium, its uses and preparation, 272, 273; the electric furnace, 273; need for cheap current, 273; Kinlochleven, 274; Blackwater dam and lake, 274, 275; the aqueduct—conduit and pipe lines, 275; an ingenious pipe joint, 275, 276; Pelton wheels, 276; governing the flow, 277; the power-house and generators, 277.

Klondike, gold discoveries at, I., 21.

Körting gas engines, I., 215, 221–224.

Krupp cemented armour, I., 390, 391, 399.

L

LABOUR, native, for African Transcontinental Telegraph, I., 195, 196.
Labour-saving machinery, *see* "Agricultural Engineering," "Remarkable Machinery used in the manufacture of Iron and Steel," "Dredgers," "Excavating Machinery," "Steam Shovels," "Track Throwers."
Ladle cranes, III., 267.
Lake Bennett, I., 29.
Lambert, the diver employed on the Severn Tunnel works, I., 83, 84.
Langdon, Shephard, and Co., contractors for the construction of part of the Canadian Pacific Railway, I., 262, 263.
"La Patrie," "La République," and "La Ville de Paris" airships, III., 56, 57, 58.
Last spike driven—of first American transcontinental railway, III., 139; of Canadian Pacific Railway, I., 282, 283; White Pass Railway, I., 32.
Launching a ship, II., 75–78.
Lebaudy airship, III., 56.
Leigh, John George, on "The Panama Canal," II., 129; on "The Water-Power Stations of Niagara Falls," II., 295; on "The Water Supply of New York," III., 97.
Lengthening ships, III., 125.
Leonardo da Vinci, inventor of canal locks, III., 167.
Lesseps, Count Ferdinand de, I., 155; conceives idea of Suez Canal, I., 241; surveys the route, I., 243; visits Constantinople, I., 243; wins over the Khedive, I., 244; visits England to raise funds for constructing the Suez Canal, I., 244; turns first spadeful of sand at Port Said, I., 244; his estimate of traffic that would pass through the canal, I., 248; his connection with first and second Panama Canal companies, II., 132; draws out plans for a railway from Orenburg to Tashkent, II., 375; delivers oration at inauguration ceremony of the statue of Liberty, New York, III., 256.
"Lift" of kite, III., 5.
Lighthouse, the Story of the, I., 370–384.
Bell Rock lighthouse, 373; Bishop Rock iron lighthouse, 378; Bishop Rock granite lighthouse, 379; great difficulties encountered, 379, 380; external casing added, 380; landing the stones, 381; fixing the stones, 381; safety nets needed, 382; violence of the waves, 384; Dhu Heartach lighthouse, 374; early modern lighthouses, 370; Eddystone lighthouse—Winstanley's, 371; Rudyerd's, 371; Smeaton's, 371; new, 375; Pharos of Alexandria, 371; Skerryvore lighthouse, 374; Wolf Rock lighthouse, 375.
Lighthouse's stability depends on weight, not adhesion, I., 373.
Lilienthal, Otto, experimenter in aviation, III., 6.
"Lines" of Carnac, I., 7.
Lining, iron—for tunnels, I., 56, 308, 309; for petroleum wells, II., 328; for water wells, III., 337.
Lions attack workmen on Cape to Cairo Railway, II., 156; at Tsavo, Uganda Railway, II., 56, 57; blockade operator of the African Transcontinental Telegraph, I., 200.
Liquid fuel and its uses, II., 340.
Liverpool Salvage Association, I., 42.
LOCKS:
Assouan dam, II., 398; Barton, I., 160; Chesapeake and Ohio Canal, III., 175; dock entrance, II., 177, 184, 185, 186; Eastham, I., 158; Illinois and Michigan Canal, III., 174; Irlam, I., 153; Mode Wheel, I., 167; old style, III., 167; Panama Canal, II., 139, 144; Pennsylvania Canal, III., 175; pneumatic most recent type, III., 168, 169; Poe, III., 171, 172; Sault Ste. Marie Canal, III., 170; Weitzel, III., 171, 172.
Locomotives, Steam, of To-day, II., 193–216.
BRITISH, 193–199; COLONIAL, 200, 201; CONTINENTAL 202–206; AMERICAN, 207–210, 211, 213, 214, 215. *Classification:* FOUR-COUPLED EXPRESS—Great Eastern Railway, 194; Great Western Railway, 194; Madras Railway, 200; Paris-Orleans Railway, 203. FOUR-COUPLED "ATLANTIC" TYPE: Great Northern Railway, 195; Great Western Railway, 195; Great Indian Peninsula Railway, 201; Hungarian State railways, 203; Chicago and North-Western Railway, 208; Philadelphia and Reading Railway, 208. FOUR-COUPLED TANK: Ballycastle Railway, 199; Bavarian State railways, 206. SIX-COUPLED EXPRESS: Caledonian Railway, 196; Great Central Railway, 196; London and South-Western Railway, 197; Indian railways, 200; Italian State railways, 203; Canadian Pacific Railway, 209; London and North-Western Railway (goods), 196. SIX-COUPLED "PACIFIC" TYPE: Great Western Railway, "Great Bear," 198; Baden State, 204; Chicago, St. Paul, Minneapolis, and Omaha, 209; Pennsylvania Railroad (largest passenger locomotive in the world), 210. SIX-COUPLED "PRAIRIE" TYPE: Italian State railways, 204; Lake Shore and Michigan Railway, 209. SIX-COUPLED "MOGUL" TYPE: New York, Ontario, and Western Railway, 208. SIX-COUPLED TANK: Alsace-Lorraine railways, 206; Berlin Metropolitan Railway, 206; Northern Railway of France, 202. EIGHT-COUPLED "CONSOLIDATION" TYPE: Great Western Railway, 198; Bengal-Nagpur Railway, 201; Grand Trunk Railway, 210; Saxon State railways, 205. EIGHT-COUPLED GOODS: Great Northern Railway, 199; Lancashire and Yorkshire Railway, 199. EIGHT-COUPLED TANK: Transandine Railway, 201. TEN-COUPLED: Austrian State railways, 205; Servian State railways, 205; Buffalo, Rochester, and Pittsburg Railway, "Decapod," 210. ARTICULATED: "Johnstone" eight-cylinder compound, 210; "Fairlie," Saxon State railways, 210; "Mallet," Hedjaz Railway, 212; "Mallet," Pekin-Kalgan Railway, 212; "Mallet," Erie Railway, 213, 215; "Mallet," Southern Pacific Railway, 213, 215; "Meyer," 214. VARIOUS: "Shay," II., 214; combined rack and adhesion, II., 223; Crane, II., 223; Fell, III., 202; Uganda Railway, II., 62; ploughing, III., 290, 297.
Locomotives conveyed by road, I., 175.
Locomotives, Electric, II., 217–222.
Their place in modern transportation, II., 217; for use on crowded lines, II., 218; for tunnel work, II., 218; current used, II., 220; tested against steam locomotives, II., 220, 221; high speed trials near Berlin, II., 221; Pennsylvania Railroad, II., 222; Simplon railway, III., 160; Jungfrau railway, III., 309.
London clay, tunnelling in, I., 227, 239.
London drainage, III., 209–225; *see* "Wonderful Drainage System of London."
London Electric Power-Stations, III., 226–231; *see* "Electric Power-Stations of London."
"Loops," the, on Canadian Pacific Railway, I., 281.
Lubrication, forced, for aeroplane engines, III., 30, 31, 32, 34, 35.
Lucin cut-off, III., 143, 145.
Lusitania, the, I., 317, 318, 319, 320, 354; II., 38, 39.

M

MA'AN, Hedjaz Railway, I., 344.
Macdonald, Sir John, promoter of Canadian Pacific Railway, I., 257.
M'Farlane, John, on Manchester as an importing and exporting centre, I., 170.
Machinery used in the manufacture of iron and steel, III., 257–271.
Macintyre, Robert, on "Docks," II., 173.
M'Kechnie, James, II., 43.
Magazines of a battleship, I., 386.
Magnets, lifting, III., 262, 263.
Manchester docks, I., 167, 168.
Manchester Ship Canal, The, I., 153–171.
Scheme for, 153; alternative scheme, 155; Parliamentary powers for construction granted, 156; entrance to the Ship Canal, 159; embankments, 159–162; Runcorn docks, 164; facts and figures about the canal, 165; railway crossings, 165; Barton swing aqueduct, 166; docks, 167, 168; effects of the canal, 169, 170.
Mangin reflector, the, I., 249.
Mansergh, James, engineer of the Elan-Birmingham aqueduct, III., 189.
Marconi Towers at Poldhu, Cornwall, The, II., 438–444.
Marconi, Guglielmo, II., 439.
Matabele rebellion and the African Transcontinental Telegraph, I., 194.
Matachin, II., 134.
Mattresses—for railway across Chat Moss, I., 369; for Colorado River closure, III., 119.
Maudslay, Field, and Co., makers of Thames Tunnel shield, I., 185.
Mauretania, the, I., 319, 320, 357: II., 38, 39, 78.
Maxim, Sir Hiram, III., 6, 11; on the future of aeronautics in warfare, III., 63.
Measuring distances for the Forth Bridge piers, I., 324.
Medina, I., 339, 346.
Meissner Pasha, engineer of the Hedjaz Railway, I., 340, 345.

Menai Straits, the bridges of the, I., 142–152.
Menhirs, I., 7.
Mercury, the, I., 319.
Merv, II., 378, 381.
Metacentre, metacentric height, I., 353.
Metcalfe, Sir Charles, II., 158.
Metropolitan Life Assurance building, New York, II., 17, 19.
Metropolitan Water Board, III., 196.
Microphone, marine, I., 432.
Moir, E. W., II., 109, 118.
Mole drainer, III., 292.
Monoliths—dock wall, II., 183; Dublin harbour, II., 183, 184; Gibraltar breakwater, III., 75; La Guaira, III., 76; Zeebrugge harbour, III., 75.
Mont Cenis Pass, III., 301.
Montauk theatre, transport of, II., 446, 447.
Mormons as irrigators, II., 85; and the Central Pacific Railway, III., 138.
Mosquitoes, II., 137.
Motor, agricultural, III., 298, 299.
Motor boat, torpedo craft, I., 425.
Motor cars, racing, *see* "Development of the Racing Motor Car."
Motor, electric "waterproof," I., 430.
Motor generators, III., 229.
Mould loft, II., 68, 70.
Mules, intelligent, I., 265.
"Muskegs," or swamps, on Canadian Pacific Railway, I., 261, 264.
Myddleton, Sir Hugh, and the New River, III., 194, 195.

N

Nairobi, II., 54.
Nantes transporter bridge, I., 292.
Needle dams, III., 176.
Neutral axis of beam, I., 102.
Newcomen's "atmospheric" engine, III., 195.
Newport transporter bridge, I., 291.
New River, the, III., 193, 194, 195, 198.
New York Subway, The, II., 342–354.
Why it was constructed, 342; cost and extent, 342; location, 342; "express" and "local" train services intended, 343; shallow level tunnels, 343; normal box-type structure, 343; modifications for special reasons, 344; contract let to J. B. M'Donald, 344; organization of labour, 344; troubles with buried pipes, 345; sewer diversion, 345; excavating and building the subway, 345; an easy section, 345; a section complicated by car tracks, 346; work along Broadway, 347; car tracks carried on temporary trusses, 347; supporting the columns of the elevated railway, 348; passing through the foundations of a skyscraper, 348; tunnelling under a monument, 348; subway stations, 349, 350; automatic signals, 350, 351; the huge power-house, 351; rolling stock, 351; congestion through heavy traffic, 353; delay caused by a "cross-over," 354; multi-door cars adopted, 354; multi-track stations suggested, 354; subways of the future, 354.
New York—geography of, II., 258, 259, 260; population of, III., 97.
New York, water supply of, II., 97–112; *see* "Water Supply of New York."
Niagara Falls, water-power stations of, II., 295–311; *see* "Water-Power Stations of Niagara Falls."
Niagara, U.S.N.S., used for laying first Atlantic cable, II., 285, 286, 288, 355–357, 360.
Nile Dams and the Assouan Reservoir, The, II., 385–408.
The Nile in early history, 385; its sources, confluents, course, and fluctuations, 386; basin irrigation, 387; perennial irrigation, 388; the cotton crop, 388; primitive irrigation appliances—the Shadoof, Sakieh, Taboot, and Natala, 389. The Delta barrage, 389; a failure, 390; converted into a fortress, 390; old foundations strengthened by British engineers, 390; details of the barrage, 390; how the foundations were secured, 391; barrage usable, but further storage needed, 391. The Assouan dam and reservoir, 391; scheme and site adopted, 393; dimensions, construction, and other features of the dam, 393; weight compared with that of the Great Pyramid, 393; contract signed and work begun, 393; enclosing the site with sudds, 393, 394; drastic measures for conquering the current, 394; exposing the river bed, 395; progress, completion, and opening of the dam, 395, 397; Stoney sluices, 397, 398; locks and navigation canal, 398; aprons to withstand scour, 398. The Assiout barrage, 399; Ibrahimiyeh Canal, 399; details of the barrage, 399; how the foundations were laid, 401; quick work needed, 402; progress of work, 402; difficulties overcome, 402; joining up the two ends of the masonry, 403; barrage finished, 404. Zifta barrage, 404. Esneh barrage, 404, 405; its purpose and construction, 405; special type of sluice gates, 405; scheme for raising the Assouan dam, 405; the beautiful island of Philæ and its monuments, 406; submersion unavoidable, 406; foundations of buildings underpinned, 406; how the height of the dam was increased, 407. Conclusion: review of five great schemes, 407; their effects, increase of value in land and crops, 408.
Norwegian railway, Bergen to Kristiania, III., 347–356; *see* "Bergen-Kristiania Railway."
Nürnberg gas engines, I., 221.

O

Oil-Fields, Engineering in the World's, II., 321–341.
Engineering requirements for oil-fields, 321; huge capital invested in petroleum industry, 322; romances of "striking oil," quickly won fortunes, 322; origin and distribution of petroleum, 322; oil-field geology, 323; surface indications of the proximity of oil deposits, 323; the sacred fires of Baku, 323; asphalt deposits, 325; the Trinidad pitch lake, 325; ozokerite in Galicia, 325; Scotch oil-bearing shales, 325. Sinking oil wells, 326; dug wells of Roumania, 325, 326; discovery of petroleum deposits in the United States, 326; two main systems of well-sinking—(1) percussion, (2) rotary, 326; the percussion system subdivided into—(*a*) cable drilling, (*b*) pole drilling, 326; boring apparatus—derrick, engine, and tools, 327; the principles of boring, 327; removing sludge, 328; lining the well, 328, 329; cost of drilling, 329; recovering lost tools, 329; the violence of oil and gas under pressure, 332; uncontrollable "gushers," 332; fires in oil-fields—precautions, extinguishing apparatus, 333; magnificence of a burning "spouter," 333; extinguishing a burning well, 334. Raising oil to the surface, 334; pumping, 334; baling, 335; use of the "air lift," 336. Distillation and refining, 336; chemistry of petroleum, 336; the effect of heat on the petroleum constituents, 336; "cracking," 336; the various distillates, 336. Transport of petroleum, 336; oil pipe lines, 337; pipes rifled to minimize friction, 337; American pipe lines, 337, 338; an ingenious automatic pipe cleaner, 338; Baku-Batoum pipe line, 338; other notable pipe lines, 338; natural gas, its occurrence and value, 338, 339; oil tank ships, 339; a floating town on the Caspian Sea, 339, 340; liquid fuel and its uses, 340, 341; future of the oil industry, 341.
Oil fuel, I., 425; on Trans-Caspian Railway, II., 378.
Open-hearth method of steel making, III., 265.
Ore unloaders, III., 257, 260.
Oroya-Lima Railway, I., 126.
Oscillating marine engines, II., 35.
Otto "cycle," in internal combustion engines, I., 216.
Overland route to India, I., 242.

P

Paddles *v.* screw propellers, II., 29.
Painting the Victoria Bridge, I., 212.
Panama Canal, The, II., 129–149.
Need for piercing the Isthmus of Panama, 130; a canal for all nations, 130; construction a tremendous task, 131, 137; impetus given to scheme by discovery of gold in California, 131; old Panama railway, 131; many schemes for a canal projected, 132; first and second Panama Canal companies, 132; sale of French canal to the United States, 133; climate of the Panama Isthmus, 134; across the isthmus, 135; work done up to 1904, 135; successful fight with disease, 136; lock *v.* sea-level canal question settled, 139; Gatun lake, 139, 142; Gatun dam, the largest in the world, 140; locks, 144; enormous quantity of material to be removed, 144; army engineers take charge, 145; steady progress, 145; labour-saving machinery used—steam shovels, 146; mechanical spreaders and track-throwers, 147; New Panama Railway, 148; huge cost of the canal, 148.
Pardoe, Stephen, on "The Construction of the Canadian Pacific Railway," I., 257.

Parrott, J. R., engineer of Florida East Coast Extension Railway, I., 139.
Parseval airship, III., 61.
Paying-out gear for cable-laying—that used for first Atlantic cable, II., 285; Bright's, II., 292, 294; III., 366.
Peacock, I. M., on "Transportation Canals of the United States," III., 163.
Pearson, S., and Son, the famous contractors—Old Hudson River tunnel, II., 109; East River tunnels for Pennsylvania Railroad, 117; Vera Cruz harbour, III., 76; New Admiralty harbour, Dover, III., 78.
Pelton wheels, III., 276.
Penetrative power of 12-inch guns, I., 390.
Periscope, I., 431.
Perkins, W. T., on "The Manchester Ship Canal," I., 153; on "Great Underpinning Achievements," III., 312.
Peto, Brassey, and Betts, contractors for the Victoria Bridge, I., 214
Petroleum, *see* "Oil Fields, Engineering in the World's," II., 321-341.
Pharos of Alexandria, I., 370.
Philæ, island of, II., 405.
Phillips, Horatio, experimenter with aeroplanes, III., 6, 7.
Picking-up gear for cable-laying, II., 369; III., 368.
Piers for Forth Bridge towers, I., 325, 326, 328.
Pile-driving—bridges of Canadian Pacific Railway, I., 279; Lucin cut-off trestles, III., 145; Manchester Ship Canal, I., 160-162; New Erie Canal works, III., 169; with water jet, II., 121.
Piles—for Dover harbour works, III., 79; reinforced concrete, II., 426, 427; screw, II., 113.
Pilot tunnel, I., 58; II., 109.
Pintsch lightbuoys on Suez Canal, I., 249.
Pipe cleaner, automatic, for oil pipe lines, II., 338.
Pipe joints—aqueduct syphons, III., 185; "muff" for very high pressures, III., 275, 276
Pipe lines — Kinlochleven, III., 275; petroleum, II., 337, 338; *see* also "Aqueducts."
Pipes for—aqueduct syphons, III., 185; London water mains, III., 206.
Planer, a huge metal, II., 382.
Plate girders, I., 104.
Plating a ship, II., 74.
Platte River, II., 89.
Ploughs, steam, III., 290, 291, 298.
Plymouth breakwater, III., 70-72.
Pole, F. J. C., on "The Construction of Fishguard Harbour," I., 172; on "The Conversion of the Gauge of the Great Western Railway Main Line," I., 108; on "The Royal Albert Bridge at Saltash," I., 34.
Poling boards, I., 186 (Thames Tunnel), 306.
Port Said, I., 245.
Portugaleti transporter bridge, I., 289.
Posilippo, grotto of, I., 19.
POWER STATIONS:
Caban Coch dam, III., 189; Chicago drainage canal, III., 174; elevated, in steel frame building, II., 15; Jungfrau railway, III., 307; Kinlochleven, III., 277; London, *see* "Electric Power-Stations of London," III., 226-231; New York subway, II., 351; Niagara Falls, *see* "Water-Power Stations of Niagara Falls," II., 295-311; Roosevelt dam, II., 100.
Price's rotary excavator, I., 58, 301, 302, 303.
Producers, gas, I., 217.
Propellers, aerial, III., 41-44.
Propelling Machinery of a Ship, The, II., 29-43.
Paddle *v.* screw, 29; increase in boiler pressures, 29; expansive working of steam, 30; Scotch and water-tube boilers, 31, 32; forced draught, 33; quadruple expansion engines, 33; the condenser, 35; paddle engines, 35; oscillating engines, 35; diagonal direct-acting engines, 36; marine steam turbines, 36; Curtis, Rateau, and Zoelly turbines, 36; Parsons marine turbine, 36, 37; turbines of *Lusitania* and *Mauretania*, 38, 39; boilers of *Lusitania* and *Mauretania*, 39; combination of piston engines and turbines, 40-42; internal combustion engines, 42, 43.
"Propulsive coefficient," I., 356.
Protection of banks of Suez Canal, I., 249.
Pumping engines—sewage, III., 221, 224; water, 201, 203, 204, 206.
Pumping—petroleum, II., 334; water from *Gladiator*, I., 46.
Pumping stations—sewage: Abbey mills, III., 221; Crossness, 224; Deptford, 224; Lot's Road, 223, 224; North Woolwich, 223—water: Lee Bridge, 203, 204, 206.
Pyramids of Egypt, I., 9, 13, 14.

Q

QUEENSFERRY, South and North, I., 321, 325.
Quicksand, II., 117.

R

RACE between electric and steam locomotives, II., 221.
Races, motor car, III., 321-334; *see* "Development of the Racing Motor Car."
Rail joints, self-adjusting, on Forth Bridge, I., 336.
Railway Brakes, II., 246-251.
Railway of the Far North, A, I., 21-33.
Discovery of gold on the Yukon River, 21; rush to Klondike, 22; difficulties of travel, 22; exciting times at Skaguay, 23; "Soapy" Smith, 23; the White Pass trail, 24; frauds perpetrated on Indian guides, 24; sufferings of baggage animals, 25; the trail covered with dead horses, 25; a railway projected, 25; details of the route, 25; work commenced, 25; legal difficulties at Skaguay, 26; tame bears in camp, 26; labour troubles, 27; intense cold hinders work, 27; first train reaches Summit, 27; the sleigh trail, 28; fleet organized for the Yukon traffic, 28; first train reaches Lake Bennett, 29; a remarkable year's work, 29; the Yukon River waterway, 29; preparations for second winter's work, 30; trouble with frozen ground, 30; progress along Lake Bennett, 32; last spike driven, July 29, 1900, 32; details of the railway, 32; gradients, 32; bridges, 33; alignment, 33; snow-ploughs, 33.
RAILWAYS:
Alpine, *see* "Two Remarkable Alpine Railways," III., 301-311; Barmen-Elberfeld, *see* "Barmen-Elberfeld Railway," II., 125-128; Beira-Salisbury, II., 155; Bergen-Kristiania, *see* "Bergen-Kristiania Railway, The Construction of the," III., 347-356; Canadian Pacific, *see* "Canadian Pacific Railway, The Construction of the," I., 257-286; Cape to Cairo, *see* "Cape to Cairo Railway," II., 150-162; Central Pacific, *see* "Construction of the first American Transcontinental Railway," III., 129-147; Fell, III., 301-306; Hedjaz, *see* "Hedjaz Railway, The," I., 339-349; Jungfrau, III., 306-311; Orenburg-Tashkent, II., 381; Oroya-Lima, I., 126; Panama, new, II., 148; Panama, old, II., 131; Snaefell, III., 302; Trans-Caspian, *see* "Russian Railways in Central Asia," II., 375-381; Trans-Siberian, *see* "Trans-Siberian Railway, The," III., 81-95; Tube, of London, *see* "Tube Railways of London, The," I., 226-240, 300-311; Underground Freight, of Chicago, *see* "Underground Freight Railways of Chicago, The," I., 359-367; Uganda, *see* "Uganda Railway, The," II., 50-64; Union Pacific, *see* "Construction of the First American Transcontinental Railway, The," III., 129-147; Wengeralp, III., 306; Wetterhorn, *see* "Wetterhorn Aerial Railway, The," II., 189-192; White Pass and Yukon, *see* "Railway of the Far North," I., 21-33.
Rainfall of India, III., 233, 246.
Reaping machines, III., 293, 297.
Reclamation Act, promoting irrigation in the United States, II., 93.
Record-breaking in laying railway track, II., 151, 159.
Refining petroleum, II., 336.
Reflector, Mangin, I., 249.
Reinforced concrete armour, I., 403.
Reinforced Concrete Construction, II., 418-432.
Stone and brick work, 418; cast-iron introduced for beams and columns, 419; steel beams adopted, 419; what concrete is, and how made, 419, 420; Portland cement, its manufacture and advantages, 420; what reinforced concrete is, 421; disposal of materials, 421; cost of reinforced concrete as compared with steel, 422; stresses in a beam, 422; distribution of steel bars in a reinforced concrete beam, 423; properties of concrete and steel, 424; their expansion, tensile strength, etc., 424; many uses of reinforced concrete, 425; reinforced concrete columns, 425; arrangement of steel bars in reinforced concrete columns, 426; reinforced concrete piles, 427; many uses for reinforced concrete, 428; the new General Post Office buildings, 430-432.

Remarkable Machinery used in the Manufacture of Iron and Steel, III., 257–271.
Steel-works' machinery, 257; Hulett ore unloader, 257, 258, 259; special ore-carrying boats, 259; another type of unloader, 260; blast furnaces, 261; automatic ore tips, 262; lifting magnets and "skull crackers," 262, 263; Bessemer steel-making process, 263, 264; the open-hearth steel-making process, 265; tilting furnaces, 265; mechanical furnace chargers, 267; ladle cranes, 267; ingot extracting machines, 268; rolling mills, 269, 270; slab chargers, 270, 271; plate-cutting shears, 271; Goliath cranes, 271.
Renard and Krebs' dirigible balloon, III., 1, 51.
Rennie, John, and the Plymouth breakwater, III., 71, 72.
R.E.P. monoplane, III., 28.
RESERVOIRS:
Ashokan, III., 104; Assouan, II., 391, foll.; balancing, in aqueducts, III., 179, 181; Beachcroft, Honor Oak, III., 201–203; Blackwater, Kinlochleven, III., 275; Chenab Canal escape, III., 236; Chingford New, III., 198, 199; Frankley, III., 191; Indian, III., 244; Jerome Park, III., 100; Lake Fife, III., 246; Lake Whiting, III., 245; Liverpool aqueduct, III., 181; Marikanave, III., 246; Mugdock, III., 179; Old Croton, III., 99; Prescot, III., 180; Staines, III., 198; Walthamstow, III., 206.
Retrieving tools and pipes from oil wells, II., 329; artesian water wells, III., 340–342.
Rhodes, Cecil, and Zambesi Bridge, I., 91; and African Transcontinental Telegraph, I., 193, 194, 195, 203; and Cape to Cairo Railway, II., 150–153, 158.
Ribbands in shipbuilding, II., 71.
Rice-growing in United States, II., 83, 85.
Richardson, Charles, I., 80.
Richardson, Wigham, I., 312.
Rims, detachable, on motor cars, III., 330.
River Tunnels of New York City, The, II., 102–123.
Sub-river tunnels of London and New York compared, 103; need for sub-river communication, 104. CROTON AQUEDUCT TUNNEL, 105; driven in the dry at great depth, 106. EAST RIVER GAS TUNNEL, 106; fault in river bed discovered, 106; a check, 107; compressed air adopted, 107; very fluid mud encountered, 107; mud penetrated 108; tunnel work remarkable for high air-pressures used, 108. FIRST HUDSON TUNNEL, 105; shields considered unnecessary, 108; a disastrous blow-out drowns twenty men, 109; pilot tunnel used to advance headings, 109; an unsatisfactory method, 109; English contractors take over the work, 109; hole in river bed plugged with hay and clay, 109; money troubles stop operations in 1891, 110; work resumed, 1902, 110; mud face baked with torches, 110; headings meet, 1904, 110; south tunnel driven at phenomenal speed, 111; an amusing incident, 111. LOWER HUDSON TUNNELS, 111. PENNSYLVANIA RAILROAD HUDSON TUNNELS, 113; difficult material to pierce, 113; screw piles used to support the tunnel, 113; tunnel lined with concrete, advantages of system, 114; the shields, interesting features, 116; a curious difficulty, shield tends to rise, 116; quicksands penetrated, 116. PENNSYLVANIA RAILROAD EAST RIVER TUNNELS, 117; four tunnels driven, 117; steel caissons for shafts sunk in banks, 117; shields, 117; segment erectors, 117; great difficulties in piercing quicksands, 118; clay blanket dumped on river bed, 118; tedious and dangerous work inside the shields, 118. BATTERY TUNNELS, 119; location, 119; frequent blow-outs, 120; an astonishing escape from drowning, 120; delicate operation of altering the level of the tubes, 120, 121; foundation piles driven to support tunnel, 121. STEINWAY, BELMONT, AND HARLEM RIVER TUNNELS, 122, 123.
Roads, making, in the Norwegian mountains, III., 349, 350; Roman, I., 17, 18.
Roebling, J. A., builds Grand Trunk Railway Bridge across Niagara gorge, III., 278; builds Brooklyn Bridge, II., 260.
Rogers, A. B., I., 270; discovers pass through Selkirks, 271.
Rolling mills, III., 269, 270.
Rolling stock—Chicago freight subways, I., 367; Hedjaz Railway, I., 347, 348.
Roman aqueducts, I., 16, 17; III., 177; bridges, I., 18, 19; roads, I., 17, 18; tools and screw, I., 20.
Roosevelt, President T., and Panama Canal, II., 140, 141, 149.
Rope incline, Kikuyu escarpment, Uganda railway, II., 58.
Ropes used in railroad making, I., 27.
Ropeway in the Andes, a Wonderful Aerial, I., 119–127.
Location, 119; projection of, 121; system adopted, 121; difficulties in transporting material, 122; transporting ropes, 123; low temperatures, 123, 124; gradients of, 124; working of, 126; automatic rope-gripping device for carriers, 126; lubrication of the ropes, 127; value of the cableway, 127.
Ross, A. M., I., 205.
Rotary digger, Price's, for tunnelling, I., 301–303.
Rotherhithe Tunnel, The, I., 49–64.
Need for better cross-river facilities in East London, 49; previous schemes, the Thames Tunnel, 49; description of Rotherhithe Tunnel, 50; large diameter, 50; open approaches, 51; cut-and-cover work, 52, 53; the shafts, 54; sinking the shaft caissons, 54, 55; use of compressed air, 56; the cast-iron tunnel, 56; putting in the lining, 57; compressed air used for driving, 57; air-locks and their principles, 58; a trial or "pilot" tunnel driven ahead, 58; the great shield for the main tunnel, 61; starting the shield from a shaft, 61; advancing the shield, 61; "grouting" the lining with cement, 61; rate of progress, 62; a second shield started, 62; tunnel opened, 63; a visit to the tunnel, first impressions, 63, 64.
Rouen transporter bridge, I., 289.
Royal Albert Bridge at Saltash, The, I., 34–40.
Designed by I. K. Brunel, 34; need for its erection, 35; facts and figures, 35; foundations for the piers, 35; sinking cylinder for central pier, 36; pier built, 36; iron work of the two main spans, a peculiar form of girder, 36, 37; scheme for floating the spans, 37; preparations made, 37; the launch, 38; first girder in position on base of piers, 38; general festivities, 39; raising the girders and building up the piers, 39; details of the bridge, 39, 40; a pathetic incident, 40.
Rudyerd's Eddystone lighthouse, I., 371.
Runcorn transporter bridge, I., 294–297.
Russell, John Scott, builder of *Great Eastern*, I., 316, 317.
Russian Railways in Central Asia, II., 375–381.
The Trans-Caspian Railway, 375; Russian pioneers in south-western Asia, 375; Russia determines to build a railway, 377; General Skobeleff subdues the Turcomans, 377; railway begun, 377; little grading to be done, 377; lack of water, supplies brought by rail, 377; encroachment of sand, measures to control it, 377; oil fuel used for engines, 378; rail-head reaches Merv, 379; bridging the Oxus—a curious oversight, 379; Samarcand reached, 379; a new Caspian terminus, 379; Russians push on from Samarcand, 379; reach Andizhan and Marghilan, 380; railway gauge and rolling stock, 380; natives as railway mechanics, 381; the Orenburg-Tashkent line, 381; future developments, 381.
Russian workmen, I., 73.
Rust joint, I., 56.

S

SACK block system of constructing breakwaters, III., 76.
Sacred fires of Surakhany, II., 323.
Saddles for suspension bridge cables—Runcorn transporter bridge, I., 295; Brooklyn Bridge, II., 261; Williamsburgh Bridge, II., 264; Manhattan Bridge, II., 270.
Safety nets—at Bishop Rock lighthouse, I., 382; at Zambesi Bridge, I., 98.
Safety switches on Canadian Pacific Railway in the Rockies, I., 278.
St. Lawrence River, I., 205.
St. Louis Bridge, The, II., 163–171.
The Mississippi River, 163, 166; an early proposal to bridge the river at St. Louis, 164; "ice gorges," 164; other physical obstacles, 164; James B. Eads's plans, 164; rival scheme frustrated, 165; details of the bridge, 165; work begun, 166; pneumatic caissons adopted, 167; terrific hurricane, much damage done, 169; the steel arch superstructure, 170; joining up, 170; the roadway, 170; completion, 170.

Sakieh, II., 389.
Salt River irrigation project, II., 98.
Saltash Bridge, *see* "Royal Albert Bridge at Saltash," I., 34–40.
Salving of H.M.S. "Gladiator," The, I., 41–48.
H.M.S. *Gladiator* is sunk, 41; scheme to raise the vessel, 42; salvage gangs get to work, 43; vessel lightened, 43; lifting "camels" built and attached to vessel, 43; vessel pumped and drawn shorewards, 44; righting operations, 44; more "camels" attached, 45; tripods affixed for hauling ropes, 45; divers stop leaks, 46; vessel floats, 46; starts for Portsmouth, 47; is safely docked, 47; a fine piece of work with a flat ending, 48.
Sand-drifts on Trans-Caspian Railway, II., 377.
Sand-washer, mechanical, III., 204.
Savannah, The, I., 315.
Scherzer Rolling Lift Bridges, II., 44–49.
Schmitt, F. E., on "The Bridges of New York City," II., 257.
Scouts (warships), I., 393.
Screening machinery, III., 170.
Screw, Roman, I., 20.
Scrive boards, II., 68.
Scrubbers for producer gas, I., 220, 221.
Searchlight at Eigerwand station, III., 310.
Seeding machines, III., 293.
Segment erectors, II., 117.
Servo-motors for torpedoes, I., 435; for governing turbines, III., 277.
Setting out a tunnel, I., 231.
Severn Tunnel, The Story of the, I., 79–89.
Dimensions, 80; shafts, 81; invaded by Great Spring, 81; Great Spring checked, 82; gradient altered, 82; pump accident, 83; divers employed to close heading door, 83, 84; Great Spring walled out, 84; telephones installed, 85; panic in the tunnel, 85; sea invades tunnel, 85; methods of tunnelling employed, 87; tunnelling completed, 88; water pumped from tunnel, 89.
Sewage, chemical treatment and disposal of, III., 215, 217.
Sewer construction, III., 219; diversion in New York, II., 345.
Sewers, intercepting, III., 211.
Sewers, London, *see* "Wonderful Drainage System of London," III., 209–225.
Sewers, storm relief, III., 213.
Shadoof, II., 389.
Shafts—Rotherhithe Tunnel, I., 54; London Tube Railways, I., 236, 237; East River Tunnels, II., 117.
Shears for cutting stout metal, III., 271.
Shield, tunnelling—Brunel's for Thames Tunnel, I., 185, 186, 187, 190; Greathead's, I., 228; East River Gas Tunnel, II., 107; lower Hudson River Tunnels, II., 111; Pennsylvania Railroad East River Tunnels, II., 116; Rotherhithe Tunnel, I., 61; *see* "Tunnelling Shield."
SHIPS AND SHIPBUILDING:
Ships—*see* "Warships," "Armament of a Battleship," "Armour of a Battleship," "Torpedo Craft, the Development of," "Submarine Boats," "Building of the Train-Ferry *Baikal*," "Designing a Ship," "Development of the Ship."
Ships—*Agamemnon*, *see* Index; *Baikal*, I., 65–79, III., 90; *Ermack*, III., 122; Egyptian, I., 312; *Great Eastern*, *see* Index; *Lusitania*, *see* Index; *Mabel Grace*, III., 128; *Mauretania*, *see* Index; *Milwaukee*, III., 126; *Niagara*, *see* Index; oil tank, II., 339; ore carrying, III., 259; *Suevic*, III., 127; telegraph, III., 362; Viking, I., 313; *Vulkan*, III., 124; warships, *see* Index; *Wittekind*, III., 125.
Shipbuilding Feats, Some Extraordinary, III., 122.
Shipbuilding terms explained—"block coefficient," I., 352; bulkheads, I., 355; "dead weight," I., 350; displacement, I., 350; equivalent girder, I., 353; "fine" and "full" lines, I., 352; "gross" and "net" tonnage, I., 352; "metacentre" and "metacentric height," I., 353; "propulsive coefficient," I., 356; "slip" of propellers, I., 357; "turret" ship, I., 354.
Shipyard, equipment of a modern, *see* "Equipment of a Modern Shipyard," II., 65–80.
"Shoots," the, I., 80.
Siberia, intense cold in, I., 72; physical features of, III., 83; rivers of, III., 85.
Signalling, Railway, II., 225–240.
Early signals, 225; semaphore signals, 226; "stepped" signals, 226; signal indicators, 227. POINTS, 227; trailing and facing points, 227; a point lock, 228; action described, 228. INTERLOCKING, 228; principle briefly explained, 229; lever locking, 229; explanation, 229, 230; catch-handle locking, 230. POWER SIGNALLING, 230; introduced by Westinghouse, 230; various agents now used, 231; electrical locking frames, 231; their advantages, 231; return indications, 232; low pressure pneumatic system, 232; automatic stroke completion, 232. AUTOMATIC SIGNALLING, 233 (*see* also II., 350, 351); most widely used in the United States, 233; electricity the primary agent, 233; principle of automatic signalling, 233, 234; the use of "overlaps," 234, 235; the series of operations performed by a train passing through successive sections, 235; automatic brake application, 235, 236; automatic signalling on steam railways, 236; typical series of signal operations traced through, 237. CONTROL OF SINGLE LINES, 237; the train staff, and its shortcomings, 237, 238; electric train staff system, 238; how a line is worked with it, 238, 239. A SYSTEM OF AUDIBLE SIGNALLING, 239; described in detail, 240.
Singer building, New York, II., 14, 17.
Sinking cylinders for Saltash Bridge, I., 35, 36.
Skaguay, I., 23.
Skerryvore lighthouse, I., 374.
Skewbacks—of Forth Bridge, I., 329, 331; of Grand Trunk Railway Bridge, III., 279; of Niagara Falls and Clifton Bridge, III., 283, 284.
Skobeleff, General, II., 377.
"Skull crackers," for breaking scrap metal, III., 262, 263.
Slab chargers, III., 271.
Slave trade and the Uganda railway, II., 50.
Sliding ways, II., 76.
"Slip" of screws, I., 357.
Sloops (warships), I., 393.
Sludge vessels, III., 217, 219.
Sluices — Assiout barrage, II., 399; Assouan dam, II., 397, 398; Delta barrage, II., 390; Esneh barrage, II., 405; Weaver, I., 164; Zifta barrage, II., 404.
Smeaton's Eddystone lighthouse, I., 371, 372.
Smiles, Dr. Samuel, on the Britannia Bridge, I., 152.
Snow-fences—on Canadian Pacific Railway, I., 265; on Bergen-Kristiania Railway, III., 356.
Snow-Ploughs, Railway, II., 241–245; on Bergen-Kristiania Railway, III., 356; on White Pass Railway, I., 33.
Snow-screens and snow-sheds—on Canadian Pacific Railway, I., 280, 281; on Central Pacific Railway, III., 136; on Fell railway, III., 305.
Snowstorm blocks work at Severn Tunnel, I., 84.
"Soapy" Smith, I., 23.
Spade, hydraulic, I., 327.
Span of telegraph wire, very long, I., 199.
Speed—of Atlantic liners, 1862–1907, I., 319; of construction of steel frame buildings, II., 4, 10; of construction of Niagara Falls and Clifton Bridge, III., 287; of destroyers, I., 422; of electric trains, II., 221, 222; of racing motor cars, III., 334.
Sphinx, I., 15.
Spinning cables of suspension bridges, II., 268–270.
Spreaders, mechanical, II., 147.
Springs, hot, in Simplon Tunnel, III., 158, 159.
Stability—of an aeroplane, III., 9, 11, 12; of lighthouses depends on weight, not adhesion, I., 373.
Stations, New York subway, II., 350, 353, 354.
Station tunnels on tube railways, I., 300.
Statue of Liberty, building the, III., 250–256.
Steam locomotives of to-day, II., 193–215; *see* "Locomotives."
Steam-shovels on Panama Canal works, II., 146.
Steam tillage, III., 289–297.
Steel-cage buildings, II., 2.
Steel-Frame Buildings, II., 1–21.
Origin of the steel-frame building, 1; definitions, 2; increase in floor space and value of ground, 3; the Crystal Palace first steel-cage building, 3; speed in construction, 4, 10; foundations, 5, 14; the steel cage, 6; the men who do the work, 6; walls and floors, 8; superiority of the steel-frame building in resisting earthquake shocks, 11; protection of steel against fire and corrosion, 12, 13; wind-bracing, 13, 14; elevated power station, 15; suspended stories in a hotel, 15; movable columns and girders, 16; lofty towers—the Montgomery Ward building, 16; Manhattan Life building, 16; Singer tower, 17; Metro-

politan Life Assurance building, 17, 19; loftier structures to come, 20; the value of the high-speed elevator, 20.
Steel-making—Bessemer process, III., 264; open-hearth process, 265.
Steel skeleton buildings, II., 2.
Stem bar of a ship, II., 73.
Stephenson, George, adopts narrow gauge for his railways, I., 109; surveys route of North Wales railway, 147; makes railway track across Chat Moss, 368, 369.
Stephenson, Robert, builds Britannia and Conway tubular bridges, I., 147–152; designs Victoria tubular bridge, 206; condemns Suez Canal scheme, 244.
Stern frame of a ship, II., 73.
Stevenson, Alan, engineer of the Skerryvore lighthouse, I., 374.
Stevenson, D. and T., engineers of Dhu Heartach lighthouse, I., 374.
Stonehenge, I., 6, 13, 14.
Stoney Sluices, II., 397, 398.
Strathcona, Lord, drives last spike of Canadian Pacific Railway, I., 282.
Stresses in a beam, I., 102–104; II., 422.
Strub rack for mountain railways, III., 307.
Stupidity of Russian officials, I., 68.
Submarine Boats, I., 427–432.
Hull of a submarine, 427; trimming, ballast, and gasolene tanks, 428; conning tower, 430; means of propulsion, 430; ventilation, 430; armament, 431; submersion, 431; the periscope, 431; "submersibles," 432; recent improvements, 432; *also* I., 396; III., 123, 124.
Submarine cables, *see* "Early Atlantic Cables," II., 277–294, 355–374; and "Cables, Submarine, The Construction and Laying of," III., 357 foll.
Subway, New York, *see* "New York Subway," II., 342–354.
Sudds, II., 393, 394.
Suez Canal, The, I., 241–256.
Early canals between the Red Sea and the Mediterranean, 241; Napoleon's scheme for making one, 242; the overland route, 242; Lesseps' scheme for a canal, 242; he surveys the route, 243; lakes available for part of canal, 243; opposition to the scheme, 243; Khedive grants permission, 244; British apathy, 244; work begun, 244; building Port Said, 245; cutting the canal, 245; labour troubles, 245; great dredgers employed, 246; the "balayeur," 247; amount of material removed, 247; canal completed, 248; cost, 248; need for improvements, 248; lighting the canal by electricity, 249; bank protection, 249; widening operations, 250; a rock-breaking dredger, 251; "gares" or sidings, 251; how stranded or sunken vessels are dealt with, 251, 252; blasting a wreck, 252; the block system of controlling traffic, 253; rules and regulations, 253; traversing the canal, 254; further improvements, 255; traffic statistics, 255; financial position of the company, 256.
Superheater, Schmidt's, II., 256.
Superheating steam, its effect and economy, II., 256.
Superstition of African natives, I., 100.
Surveying for Bergen-Kristiania Railway, III., 349; Canadian Pacific Railway, I., 258, 270, 271, 272; Chicago freight subways, I., 363; Florida East Coast Extension Railway, I., 129, 130; Gunnison canyon, II., 95, 97; Jungfrau Railway, III., 307; Simplon Tunnel, III., 155; Union Pacific Railway, III., 131.
Suspension bridges, principles, I., 106; Brooklyn, II., 260, 261; Manhattan, II., 266–270; Menai Straits, I., 142–145; Niagara Falls and Clifton, III., 278, 282–287; Williamsburgh, II., 261–266.
Swing aqueduct, Barton, I., 167.
Swing bridges on Manchester Ship Canal, I., 165.
Switches, safety, on Canadian Pacific Railway, I., 278.
Syphons in aqueducts, III., 179, 187; Severn, Birmingham aqueduct, 191; Teme, Birmingham aqueduct, 191.

T

TABOOT, II., 389.
Tabor, E. H., on "The Rotherhithe Tunnel," I., 49–64.
Tanks, experimental, for testing ship models, I., 356.
Tanks, irrigation, in India, III., 244.
Tartar, H.M.S., I., 423.
Tebuk, I., 345.
Telegraph, African Transcontinental, *see* "African Transcontinental Telegraph," I., 193–204.
Telegraph poles—iron, I., 199; erecting, I., 199; damaged by wild animals and vegetation, 200; living, on Uganda railway, II., 63.
Telegraph ships, III., 362.
Telephone installation in Severn Tunnel, I., 85; value of, 85.
Telford, Thomas, his bridge at Gloucester, I., 79; makes road from Shrewsbury to Holyhead, 142; bridges the Menai Straits, 142–146.
Teredo navalis, or wood-boring worm, Brunel's Thames Tunnel shield based upon its boring action, I., 185.
Thames Tunnel, The, I., 181–192.
An extraordinary engineering feat, 181; early schemes for tunnelling the Thames, 182; Brunel's proposal, 182; dimensions of tunnel, 182; tunnel company formed, 182; sinking first shaft caisson, 183; underpinning the caisson, 185; provision for drainage, 185; the great shield, 185; method of excavation, 186; advancing the shield, 186; a mistaken policy, 188; first irruption of the river, 189; the tunnel cleared, 189; second irruption, 189; funds exhausted, 190; Government advances money, 190; new shield installed, 190; further inroads of water, 191; a curious subsidence of ground, 191; communication established, Brunel knighted, 191; tunnel opened, 192.
Thermal efficiencies of various types of engine, I., 226.
Thompson, A. Beeby, on "Engineering in the World's Oil Fields," II., 321.
Thompson ladder excavator for tunnelling, I., 301.
Thomson, Professor William (Lord Kelvin), II., 280; his reflecting galvanometer, 293, 294; starts with second Atlantic cable-laying expedition, 355; counsels perseverance, 357; his appreciation of Sir Charles Bright's work, 364; represents Atlantic Telegraph Company on 1865 expedition, 368; and on 1866 expedition, 369.
Three-wire system of transmitting electric current, III., 227.
Threshing machines, III., 295.
Thwaite, Benjamin Howarth, discovers that blast furnace gas is suitable for use in gas engines, I., 219; invents scrubbers to clean the gas, 220; reaps no profit from his inventions, 226.
Tidal wave floods Severn Tunnel, I., 85.
Timber docks, II., 185.
Time-table of Trans-Caspian Railway, II., 381.
Titan cranes, I., 176; III., 69.
Toggles, adjustment, for bridge cantilevers, III., 281, 283, 284.
Tonnage, gross and net, of ships, I., 352.
Tools, ancient, I., 19, 20; a colossal tool, II., 382–384.
Torpedoes, I., 433–441.
General description, 433; cost, 433; the "head," 434; air-chamber, 435; balance chamber, 435; engine chamber, 436; buoyancy chamber, 436; gyroscope for steering, 436; tail section, 437; range increased by air heater, 437; speed, 437; Bliss-Leavitt torpedo, 437; firing the torpedo, 437. CONTROLLABLE torpedoes, 438; Brennan torpedo, 438; Sims-Edison torpedo, 438; wireless steered, 439; crewless submarine boats, 439, 440; torpedo nets, 440; *also* spar torpedo, 418.
Torpedo Craft, The Development of, I., 418–425.
Early types, 418; torpedo gunboats, 419; destroyers, 419; the *Turbinia*, 422; turbine driven destroyers, 422; the *Tartar* class of destroyer, 423; description of a destroyer, 424; modern torpedo boats, 424; oil fuel, 425; motor-driven craft, 425; *also* 393.
Tower subway, I., 228.
Towers of Famatina cableway, I., 122; of Forth Bridge, 323, 331, 332.
Track-throwers, mechanical, II., 147.
Traffic on Cape to Cairo Railway, II., 158.
Train-ferry *Angara*, I., 78.
Train-ferry *Baikal*, I., 65–78.
Transformers, electric current, III., 227.
Transmission lines for electric power—Electric Development Company's, II., 310; Niagara Falls Power Company's, 303; Ontario Power Company's, 306.
Transportation Canals of the United States, III., 163–176.
The value of inland waterways, 163; statistics of United States canals, 163; canals temporarily crushed by railroad competition, 164; great projects now afoot for bringing canal system up to date, 164, 165; past history of the canals, 165. OLD ERIE CANAL, 165; begun in 1777, completed 1825, 165; wane of the canal's importance, 167; electric towage tried, 167. NEW ERIE CANAL, 168; new system of pneumatic locks to be used, 168;

pneumatic lock described, 168; excavators and dredgers for the new canal works, 169; "geysers," 169; pile-driving, 170; screening, crushing, and washing plants, 170. SAULT STE. MARIE CANAL, 170; early history, 170; canal opened in 1855, 170; larger channel and locks soon required, 170; Weitzel and Poe locks, 171; facts about the canal, 172; at present the most important canal in the United States, 172. CHICAGO DRAINAGE CANAL, 172; its double purpose, 172; wonderful machinery used for excavation, 173; "channellers" and dredges, 173, 174; power-houses on the canal, 174. OTHER CANALS: Illinois and Michigan, 174; Lake Borgne Canal, opened 1901, 174; proposed Florida Canal, 175; Albemarle and Chesapeake Canal, 175; Chesapeake and Delaware Canal, 175; Pennsylvania and Ohio Canals, 175, 176; activity in the state of Ohio, 176; rivers canalized by means of movable dams, 176; principle of the needle dam, 176.

Transporter Bridges, I., 287–299.
Development of bridges, 287; the transporter bridge, 289; a primitive transporter bridge, 289; Portugaleti Bridge, 289; Rouen transporter, 289; Newport transporter, 291, 292; Nantes transporter, 292; Duluth transporter, 292, 294; Runcorn transporter, 294–297—sinking cylinders for foundations of towers, 294; the suspension cables, 295; method of attachment to anchorage, 295; the stiffening girders, trolley, and car, 297; the trolley motors, 297; table of chief transporter bridges, 297. DESIGN, 297; superstructure, 298; different construction and arrangements of cables, 298, 299; how the cables are put in position, 298; a curious effect of wind on cables, 299; car propulsion, 299.

Trans-Siberian Railway, The, III., 81–95.
Early schemes for a railway across Asia, 81; a horse tramway suggested, 81; imperial order to commence building a line issued in 1891, 82; first sod turned at Vladivostok in 1892, 82; the Russian peasant slothful but persevering, 82; population and physical features of Siberia, 83; route of the railway, with distances, 83; work divided into sections, 83; surveying the route, 83; specifications for construction, 83; rails, embankment, ballast, gradients, and curves, 84; official corruption and scamped work, 84; only Russians employed, 84; sections of the railway, 85; country easy from Urals to Lake Baikal, 85; the great rivers of Central Siberia, 85; thirty miles of bridges required, 85; the Yenisei Bridge, 85; track laid at average of more than one mile a day, 86; Siberian trains, 87; express *de luxe*, 87; very primitive accommodation for emigrants, 87; the railway stations, 87; Omsk, 87; the Obi Bridge, 87; the "Taiga," 87; why the railway did not pass through Tomsk, 88; the penalties of independence, 88; Krasnoiarsk, 89; Yenisei Bridge, 89; Lake Baikal, 89; temporary methods of maintaining traffic across the lake, 89; sledges used in winter, 90; dangers of sledging, a gruesome incident, 90; the *Baikal* and *Angara* train-ferries, 90; trans-Baikal section, route modified, 90; crossing the Yablonoi Mountains, 91; Manchurian Railway, 91; "East Chinese section," to Vladivostok, 91; branch line from Harbin to Port Arthur, 92; subsequently captured by Japanese, 92; Ussuri Railway from Vladivostok to Khabarovsk, 92; the Baikal Ring Railway round south end of lake—great difficulties to be overcome, 92; much tunnelling and blasting required, 93; Italian workmen imported, 93; work let to contractors, 93; careless workmen and frequent accidents, 93; heavy rails used for Baikal section, 93; the railway an important factor in the Russo-Japanese War, 94; the railway to-day, 94; mail traffic to the Far East, 94; train robbers, 94; future of the railway, 94, 95.

"Travellers" for bridge erection—Blackwell's Island Bridge, II., 272; Niagara Arch Bridges, III., 282, 284.

Traverse lines, in tunnel surveying, I., 231.

Trial trip of a destroyer, I., 395, 396; of a ship, II., 80.

Trusses, bridge—"king," I., 105; lattice, I., 105; "queen," I., 105; timber, in New York subway, II., 347; Warren, I., 105.

Tube Railways of London, The, I., 227–240, 300–311.
Need for relieving congestion in London streets, 227; Barlow's proposed "omnibus" tunnels, 227; the Tower subway, 228; City and South London Railway, 229. LONDON TUBE RAILWAYS, 229; approximate length in miles, 229; gauge, diameter of train tunnels, 229, 230. MATHEMATICS OF TUNNELLING, 230. SETTING OUT A TUNNEL, 231; "traverse" lines run over the surface, 231; careful measurement with steel tape, 231; the plan, 231; transferring surface lines below ground, 231, 232. GUIDING SHIELDS, 232; on the straight, 232, 233; steering round a curve, 233; proportionally divided guide rods, 233; "offsets," 233, 234; setting out tangents, 234; vertical steering, 234, 236. SHAFT SINKING, 236: diameters of shafts, 236; the "underpinning" method, 236; use of a cutting edge, shaft lining sunk by its own weight, 236; shield method of sinking, its success, 237. TUNNELLING: various methods employed under different conditions, 238; the London clay an ideal material to tunnel through, 238; the Greathead shield, its various parts, and how it is used, 239, 240; station tunnels, 300; details of, 300, 301. THE ROTARY DIGGER, 301; two types of mechanical excavators tried, 301; Price's rotary digger, first type, 301; improved type, 301; the digger's efficiency, 302; gradual increase in working speed, 302; Greathead and rotary shields compared, 303. TUNNELLING THROUGH WATER-BEARING STRATA, 303; compressed air used to exclude water, 303; its adoption first suggested by a British admiral, 303; the air lock, its principle and construction, 304; passing through an air lock, 305; shaft sinking and tunnelling with compressed air not equally simple, 305; a difficulty in tunnelling due to differences of pressure, 306. CIRCUMVENTING DIFFICULTIES, 306; Greathead's "assisted shield" method for loose ground, 306; Dalrymple Hay's "clay pocket" system, its success, 307; a blow-out and its curious consequences, 308. ERECTING IRON TUNNEL LINING, 308; placing a segment, 309; grouting a ring with cement, 309. METHODS OF GETTING RID OF WATER FROM TUNNELS: usual course to provide a small drainage tunnel as dump, 309; borehole into chalk tried successfully, 310. GRADIENTS, 310; "dipping" gradients used where possible, 310, 311; stations situated at summits, 311; maximum acceleration obtained and minimum braking required, 311; various relative positions of two running tunnels, 311; steepest gradients, 311.

Tubes—for St. Louis Bridge arches, II., 170; for Forth Bridge members, I., 331.

Tunnel for gas mains, East River, II., 106, 107.

TUNNELLING:
Ancient, I., 19; baking mud at working face, II., 110; correcting line after construction, II., 114, 120, 121; draining, I., 309; drills, *see* "Drill, Rock Boring;" lining, I., 308; mathematics of, I., 230; methods of in Alpine tunnels, III., 153, 155, 156; pilot, I., 58; II., 109; quicksand, II., 117; setting-out, I., 231, 232; shield—Thames Tunnel, I., 57; Greathead, I., 228, 239, 240, 303; steering, I., 232–236; speed—increase shown by successive Alpine tunnels, III., 153; phenomenal, in Hudson River Tunnel, II., 110; winter work, III., 352, 355.

TUNNELS, RAILWAY AND ROAD:
Arlberg, III., 152, 153; Battery, New York, II., 119–121; Blackwall, I., 182; Central Pacific Railway, III., 137; Chicago subways, I., 363, 364; Gravehals, III., 349, 354; Hudson River, first, II., 105, 109–111; Jungfrau railway, III., 307, 310; Loetschberg, III., 162; London tube, *see* "Tube Railways of London;" lower Hudson, II., 111, 112; New York River, *see* "River Tunnels of New York City," II., 102–123; Pennsylvania railways, II., 113-118; Rotherhithe, *see* "Rotherhithe Tunnel," I., 49–64; St. Gothard, III., 151, 152; Severn, I., 79-89; Steinway, II., 122; Tauern, III., 162; Thames, I., 49, *see* "Thames Tunnel," I., 181-192; Union Pacific Railway, III., 135.

TUNNELS, WATER:
Croton aqueduct, II., 105; Cynynion, Liverpool aqueduct, III., 182; Dolau, Birmingham aqueduct, III., 191; Electrical Development Company's, II., 308, 309; Foel, Birmingham aqueduct, III., 191; Gunnison, II., 95, 97, 98; Hirnant, Liverpool aqueduct, III., 182; Knighton, Birmingham aqueduct, III., 191; Llanforda, Liverpool aqueduct, III., 182; Niagara Falls Power Company's, II., 301; Periyar, III., 245; Thirlmere aqueduct, III., 183.

Turbines, steam—advantages of, II., 36; Curtis, II., 36; combined with piston engines on ships, II., 40, 41; Parsons, II., 36–38; III., 231; Rateau, II., 36; Zoelly, II., 36.

Turbines, water, II., 300, 302, 304, 306.

Turbinia, I., 422.

Twelvetrees, W. Noble, on "Steel-Frame Buildings," II., 1–21; on "Reinforced Concrete Construction," II., 418–432; on "The Story of the Lighthouse," I., 370–384.

Tyres, motor car, III., 327.

U

Uganda Railway, The, II., 50–64.
The title a misnomer, 50; first suggestion for the line, 50; decision to connect Victoria Nyanza with Mombasa, 51; construction advocated by prominent statesmen, 51; preliminary survey made, 53; line commenced in 1895, 53; Salisbury Bridge, 53; gauge of line one metre, 54; first section to Nairobi described, 54; Nairobi, its quick growth, 54; difficult construction in hills west of Nairobi, 54; Indian coolies imported, 55; Uganda railway an extraordinary feat of engineering, 55; great elevation attained, 55; adventures with lions at Tsavo, 56; lions cause the shifting of the construction camp, 56; fatal carelessness, 57; a humorous incident, 57; an extraordinary notice, 57, 58; the Kikuyu escarpment and the Mau Valley, 58; tremendous gradients, 58; much bridging needed, 59; construction delays, 59; marauding natives and measures to outwit them, 59, 61; locomotives, water supply, and rolling stock, 62; "wash-outs," 63; living telegraph poles, 63; the railway a credit to all concerned, 63, 64; table of distances, 64.

Uncompahgre irrigation project, II., 95–98.

Underground Freight Railways of Chicago, The, I., 359–367.
An underground distribution system needed, 360; what the system has effected, 360; constructional difficulties, 361; work done quietly, 362; "telephone" tunnels, 362; surveying the streets, 363; building the subways, 364; removing excavated material, 365; direct connection with warehouses, 365; carrying the mails, 365; extent of subways and equipment, 367.

Underpinning—churches, *see* "Great Underpinning Achievements," III., 312; shafts of Thames Tunnel, I., 185; shafts of tube railways, I., 236; skyscraper, II., 348.

United States, irrigation in the, *see* "Irrigation Work in the United States," II., 81–102.

V

VACUUM brake, II., 246–248.

Valve gears—Joy, II., 251; Stephenson, 245; Walschaert, 256.

Valves, automatic, in aqueduct pipe lines, III., 187, 188.

Van Horne, Sir William, I., 268.

Ventilation, tunnel—Arlberg, III., 154; St. Gothard, 153; Simplon, 156, 160.

Viaducts of Florida East Coast Extension Railway, I., 133.

Victoria Bridge, The Great, I., 205–214.
The St. Lawrence a great obstacle to intercommunication, 205; A. M. Ross draws out plans, 206; Robert Stephenson visits Canada to examine site, 206; ice "shovings," 206; work begins, 207; hygienic difficulties, 208; dams carried away by ice, 208; financial troubles, 209; preparations for building the tubes, 210; careful manufacture, 210; the end in sight, 210; working against time, 210; disaster threatened, 211; tube completed just in time, 211; a description of the operations, 212; painting the tubes, 212; bridge opened, 213; a graceful act, 214.

Victoria, Vancouver Island, I., 285.

Victoria Falls described, I., 90, 92; II., 154; *see* "Zambesi Bridge, The Great," I., 90–101.

Viking ship, I., 313.

Voisin biplane, III., 21, 23.

W

WALKER, T. A., contractor for Severn Tunnel, I., 81, 84, 88, 89; contractor for the Manchester Ship Canal, I., 157.

Warrior, the, I., 399.

Watts, Sir Philip, I., 390.

Warships, I., 385–396.
The BATTLESHIP, 385; defensive qualities, 385; ordnance *v.* armour, 386; magazines, 386; new battleships, 388; H.M.S. *Dreadnought*, 388; the *Dreadnought's* guns, 388; penetrative power of 12-inch gun, 390; speed of battleships, 390; advantages of turbine machinery, 390; cost of warships, 390. PROTECTED cruisers, 391. ARMOURED cruisers, 391. SCOUTS, 393. SLOOPS and GUNBOATS, 393. TORPEDO craft, 393; fast destroyers, 395; a destroyer's trials, 395. SUBMARINE boats, 396.

Warship of the Future, The, I., 453–456.

Warship, salving a, *see* "Salving of the *Gladiator*," I., 41–48.

Washington, George, and the canals of the United States, III., 163, 165.

Water-jet for pile-driving, II., 121.

Water-Power Stations of Niagara Falls, The, II., 295–311.
Niagara River and Falls, 295; physical features of the river, 296; and falls, 296; early history of power development, 298. HYDRAULIC POWER AND MANUFACTURING COMPANY: formed in 1877, 299; hydro-electric installation, 1881, 299; power station No. 2, 1895, 303; power station No. 3, 1903, 303; description of stations, 304. PRINCIPLES of a hydraulic power station, 299, 300. NIAGARA FALLS POWER COMPANY, 300; intake, 300; wheel pit and penstocks, 301; generators and automatic governors, 301; turbines and generators, 302; transformers, 302; distribution of current, 303. CANADIAN COMPANY, 303; controlled by Niagara Falls Power Company, 303; the plant, 303. ONTARIO POWER COMPANY, 305; huge conduits, 6,300 feet long, 305; the intake, 306; power station, 306; distributing station and transmission lines, 306, 307. ELECTRICAL DEVELOPMENT COMPANY, 307; two bold and original conceptions, 308; wonderful engineering at the intake, 308; wheel pit and turbines, 308; discharge tunnel emptying behind the falls, 309; a remarkable experience for visitors, 309; power house, 309; transmission line, 310; are the Falls imperilled? 310; industries at Niagara Falls, 310; wonderful activity, 311.

Water Supply of London, *see* "How London gets its Water," III., 193–208.

Water Supply of New York City, The, III., 97–112.
New York's demand for water, 97; growth of population, 97; first CROTON River project, 98; the old Croton dam, 98; first Croton aqueduct, 98; second pipe line laid to increase supply, 99; fresh schemes, 99; Board of Aqueduct Commissioners formed, 99; New CROTON project, 99; the aqueduct, 100; New Croton dam, 101; a probable catastrophe avoided, 101; huge dimensions of the dam, 101; material excavated, 101; Cross River dam, 102; present daily consumption of water in New York, 103; further supply called for, 103; Catskill Mountains selected as gathering ground, 103; tenders called for, 104; the ASHOKAN reservoir, 104; central weir and dikes, 105; the Olive Bridge dam, 105, 106; estimates of cost of scheme, 106; features of the dam, 106; expansion and contraction joints, 106, 107; the reservoir basin, 107; CATSKILL aqueduct, its course to Staten Island, 108, 109; a colossal enterprise, 109; facts and figures, 109; exploratory work, 110; twenty-five miles of trial borings, 110; list of syphons, 111; the Hudson River a serious obstacle, 111; trial boring 1,030 feet deep does not reach sound rock, 111; provision for future increase in supply, 111, 112.

Water-tight compartments, I., 390.

Water towers—Lake Vyrnwy, III., 181; Norton, 181.

Watt, James, improves steam engines, III., 195.

Waves—force of, I., 380, 384; III., 65, 67, 72, 74; nature of, III., 65.

Wax experimental models of ships, I., 356.
Weaver sluices, I., 160, 164.
Webster, John J., on "Transporter Bridges," I., 287–299.
Weirs—Bari Doab Canal, III., 240; Chenab River, 238; Lake Fife, 246; shutters, 238.
Wellington, Duke of, supports the Thames Tunnel scheme, I., 190.
Wells—petroleum, *see* "Oil-Fields, Engineering in the World's," II., 321–341; water, *see* "Artesian Wells, and How they are Bored," III., 335–346; wells in Kent, III., 196.
Westinghouse air brake, II., 248–251.
Wetterhorn Electric Aerial Railway, The, II., 189–192.
Wheeler, Albert G., I., 362, 367.
White Horse Rapids, I., 28, 29.
White Pass and Yukon Railway, *see* "Railway of the Far North," I., 21–33.
Williams, Archibald, on "Ancient Engineering," I., 5–20; "The Salving of H.M.S. *Gladiator*," I., 41–48; "The Story of the Severn Tunnel," I., 79–89; "The Great Zambesi Bridge," I., 90–101; "A Wonderful Aerial Ropeway in the Andes," I., 119–127; "The Bridges of the Menai Straits," I., 142–152; "The Thames Tunnel," I., 181–192; "The Great Victoria Bridge," I., 205–214; "The Story of the Forth Bridge," I., 321–337; "The Conquest of Chat Moss," I., 368, 369; "Scherzer Rolling Lift Bridges," II., 44–49; "The Barmen-Elberfeld Railway," II., 125; "Railway Brakes," II., 246–251; "Theory and Principles of the Aeroplane," III., 5–13; "Flying Machines of To-day," III., 15–28; "Aeronautical Engines," III., 29–37; "The Construction of Aeroplanes and Propellers," III., 39–44; "Dirigible Balloons," III., 45–63; "Harbour Construction," III., 65–79; "The Great Tunnels through the Alps," III., 148–162; "Great British Dams and Aqueducts," III., 177–192; "How London gets its Water," III., 193–208; "The Wonderful Drainage System of London," III., 209–225; "The Kinlochleven Works of the British Aluminium Company," III., 272–277; "The Arch Bridges of Niagara Falls," III., 278–287; "Agricultural Engineering," III., 288–299.
Williams, Leslie, on "The St. Louis Bridge," II., 163–171.
Williams, Sir Edward Leader, I., 153, 155, 166, 171.
Wilson, J. S., on "The Nile Dams and the Assouan Reservoir," II., 385–408.
Wilson, Professor Erasmus, II., 24.
Winchester Cathedral, underpinning of, III., 312–315.
Winstanley's lighthouse, I., 370, 371.
Wireless telegraphy, I., 202; III., 376.
Wolf Rock lighthouse, I., 375.
Wonderful Drainage System of London, The, III., 209–225.
Drainage the complement of water supply, 209; the problem of draining London, 209; the old rain sewers and house cesspools, 211; difficulty of discharging sewage into the Thames, 211; reforms urgently needed, 211. Scheme of INTERCEPTING SEWERS authorized in 1856, 211; the scheme, 211, 212; storm relief sewers, 213; pollution of Lower Thames, 214; inquiries held, 214; chemical treatment of sewage introduced, 215. BARKING OUTFALL works, 215; precipitation channels, 215; sludge and sludge vessels, 217; dumping sludge at sea, 219; new sewers, 219; sewer construction, 219; figures of discharge capacity of sewers, 221; sewer men's duties and dangers, 221. PUMPING STATIONS, 221; Abbey mills, 221; Lot's Road, 223, 224; Crossness, 224; other stations, 224; surprising figures, 224; effect of good drainage on public health, 224.
Workmen, Indian and Burmese, II., 434.
Wright, the brothers, III., 11, 12; early experiments, 15, 16; first flights, 17; records, 17; their aeroplane described, 18, 19; their engine, 30.

Y

YELLOWSTONE River, II., 89.
Yukon River, I., 21, 22.

Z

Zambesi Bridge, The Great, I., 90–101.
Site of, 91; design, 92, 93; bearings and skewbacks, 94; cableway at, 95; foundations, 96; method of building, 97; arch span joined, 98; painting, 100; testing, 100; appearance of the bridge, 101.
Zambesi River, I., 90.
Zeppelin, Count F. von, III., 1; his dirigible balloons, 48, 49, 52–56.

LIST OF ILLUSTRATIONS.

A

AERONAUTICAL ENGINES:
Anzani, three-cylinder, III., 32.
Bayard - Clément, seven - cylinder, III., 34.
Four-cylinder for airship, III., 38.
Fiat, eight-cylinder, III., 37.
Gnome, seven-cylinder, III., 33.
Gobron, eight-cylinder, III., 37.
Green, four-cylinder, III., 31, 32.
Pipe, eight-cylinder, III., 37.
Wolseley, eight-cylinder, III., 36.
Wright, four-cylinder, III., 31.
Zodiac III.'s, III., 63.
AEROPLANES:
CONSTRUCTION:
Double-surfaced deck, III., 41.
Scene in factory, III., 40.
Single-surfaced deck, III., 39.
THEORY:
Angle of descent, III., 8.
Diagram showing forces acting on oblique surface, III., 6.
Section of deck, III., 6.
MACHINES:
Antoinette monoplane—
Diagram of, III., 28.
In flight, III., 26, 28.
Tuning up, III., 13.
Blériot monoplane—
Diagram of, III., 27.
Carriage of, III., 27.
In flight, III., 25.
Cody biplane—
Diagram of, III., 24.
In flight, III., 14.
Curtiss biplane, III., 22.
Farman biplane—
Diagram of, III., 23.
At rest, III., 23.
Carrying two persons, III., 10.
Voisin biplane—
Diagrams of, III., 21.
At rest, III., 15.
In flight, III., 20, 22.
Wright biplane—
Diagram of, III., 18.
On starting rail, III., 19.
In flight, III., 4, 16.
Agamemnon, H.M.S., II., 356, 359.
Agricultural machinery:
Combined harvester and thresher, horse drawn, III., 295.
Combined harvester and thresher, steam propelled, III., 296.
Disc plough, III., 291.
Gang plough, steam drawn, III., 298.
Grain elevator, III., 297.
"Header," for reaping corn, III., 294.
Heath plough, III., 292.
Ivel agricultural motor, III., 299.
Mole drainer, III., 293.
Plough engines, Fowler's, III., 289.
Punt ploughing tackle, III., 290.
Ridger, III., 291.
Threshing machine, old fashioned, III., 288.
Threshing machine, modern, Salt River valley, III., 294.
Trenching machine, III., 292.
Air-locks:
Medical, II., 107.
Rotherhithe Tunnel, I., 56.
Runcorn Bridge foundations, I., 298.
Ammunition hoists on warship, I., 447.
Anchor, *Mauretania's*, II., 68.
Anchorage for cables of bridge, I., 299; II., 264, 265, 267.
Angara, train ferry, I., 77, 78.
Apples grown on irrigated land, II., 84.
AQUEDUCTS:
Barton Swing, I., 163, 167.
Birmingham:
Cut-and-cover work, III., 184.
Lowering pipe into trench, III., 184.
Large steel pipe at Maes-y-gelli, III., 186.
Map of, III., 189.
Three pipes in trench, III., 186.
Three pipes crossing Worcestershire and Staffordshire Canal, III., 192.
Carlsbad, New Mexico, II., 94.
Catskill:
Cut-and-cover section, III., 108, 109.
Map of course, III., 107.
Steel moulds for cut-and-cover, III., 110.
Typical sections, III., 112.
Kinlochleven, III., 274.
Liverpool, map of, III., 180.
Manchester, map of, III., 187.
Roman:
Pont du Gard, I., 18.
Section of, I., 17.
Segovia, I., 16.
Solani, III., 242.
Armour of a battleship:
Armoured decks, I., 403.
Barbette, assembling, I., 400.
Barbette shield for 12-inch gun, I., 401.
Barbette shield of *Dreadnought*, I., 401.
Disposition of armour on various ships, I., 415.
Planing armour plates, I., 397.
Rolling armour plates, I., 398.
Steel communication tube, I., 400.
Artesian wells and well boring:
Air-lift, III., 345.
Bomb for dynamiting a well, III., 335.
Bourne well, III., 340.
Diver about to enter well, III., 343.
Drilling rig at work, III., 342.
Drills—shot drill, III., 339; calyx, 339.
Pumping from an artesian well, III., 344.
Sand screen, III., 341.
Sinking well in river bed, III., 337.
Spouting well, III., 341.
Tools for well-sinking—chisels, III., 338; "crow's foot," 339; latch tool, 339; rod-tiller, 338.
Artesian wells of Australia, II., 312–320:
Cambridge Downs, II., 314, 320.
Cunnamula, II., 317.
Dolgelly, N.S.W., II., 314.
Eulolo, II., 318.
Maxwelton No. 1, II., 315.
Moree, II., 319.
Noorama No. 1, II., 316.
Toorak, II., 318.
Assouan dam:
Closing sudd, II., 392.
Foundations, II., 394, 395.
Navigation canal, II., 402.
Opening ceremony, II., 397.
Plan of site, II., 391.
Sections of dam, II., 394, 408.
Sluice lining, II., 398.
Sluices, Stoney, II., 398.

B

BAALBEC, great stone of, I., 11.
Baikal, train-ferry, I., 65–72, 74, 75, 78.
Balloons, dirigible:
Clément-Bayard entering shed, III., 57.
Colonel Rénard at Rheims, III., 46.
Giffard's, III., 49.
Gross II., semi-rigid, III., 61.
Malécot, semi-rigid, III., 47.
Parseval II., non-rigid, III., 59, 62.
Renard and Krebs, III., 51.
Severo's, III., 49.
Ville de Paris, non-rigid, III., 58.
Zeppelin, III., 50, 52, 54.
Zodiac III., III., 56.
Barking outfall works, plan of, III., 214
Barrages:
Assiout, II., 399, 400, 407, 408.
Delta, II., 390.
Esneh, II., 401, 404.
Bed-plates, Forth Bridge piers, I., 331.
Beira, railway pier at, II., 155.
Bessemer converter, in blast, III., 264; section of, III., 265.
Blast furnace, III., 260; diagram of, III., 261; linked with gas engine, I., 225.
Blasting rocks at Fishguard Harbour, I., 174, 175; wreckage of *Chatham*, 252.
Block coefficient, I., 352.
"Blow out" in Thames, I., 307; in East River, New York, from Battery Tunnel, II., 119.
Boilers:
Babcock and Wilcox water-tube, II., 32, 33.
Baikal's being placed on deck, I., 73.
Chatham's, after blasting, I., 252.
Forced draught for, II., 33.

Mauretania's, II., 41.
Scotch single-ended, II., 31.
Yarrow water-tube, II., 32.
Boom across Portsmouth Harbour, I., 425.
Bo'sun's stool at work, II., 443.
Brakes:
Self-releasing, II., 291.
Vacuum automatic railway:
Air ejector, II., 247.
Carriage fitted with brake, II., 247.
Cylinders, II., 246, 249.
Valve, guard's van and rapid acting, II., 248.
Westinghouse air:
Principle explained, 250.
Triple valve, II., 249.
Breakwaters:
Dover, III., 72, 73.
Fishguard, I., 177.
South Shields, III., 68.
Vera Cruz, III., 75, 76, 77.
BRIDGES:
DEVELOPMENT:
Application of load, I., 103.
Continuous beam, I., 103.
Girder, plate, I., 104.
Bow-string, I., 104, 106.
Truss—"king" and "queen," I., 105; lattice, 106; Warren, 105.
Suspension bridge, I., 106.
Cantilever bridge, I., 107.
ARCH BRIDGES:
Grand Trunk Railway, Niagara Falls, III., 278, 279, 280, 281, 282, 284, 286.
Henry Hudson Memorial, II., 276.
Manhattan Valley, II., 275.
Niagara Falls and Clifton, III., 285.
Roman, over Danube, I., 19.
St. Louis, II., 166, 167, 168, 171.
Severn, for Birmingham aqueduct, III., 177.
Walnut Lane, Philadelphia, II., 275.
Washington, II., 275.
Zambesi, I., 93, 94, 95, 96, 97, 98, 99, 100.
CANTILEVER:
Blackwell's Island, II., 271, 272, 273, 274.
Forth, I., 321, 322, 324, 326, 329, 330, 331, 332, 333, 334, 337 (in London).
Switchback canyon, I., 31.
SCHERZER ROLLING LIFT, II., 44, 45, 47, 48, 49.
SUSPENSION:
Brooklyn, II., 260, 261.
Manhattan, II., 265, 267, 268, 269, 270, 271.
Menai, I., 144, 145.
Williamsburgh, II., 257, 262, 263, 264, 265, 266.
SWING:
Barton, aqueduct, I., 163.
TRANSPORTER:
Ancient, I., 288.
Marseilles, I., 294.
Middlesborough, I., 288.
Nantes, I., 292, 293.
Newport, I., 291.
Portugaleti, I., 290.
Rouen, I., 290.
Runcorn, I., 295, 296, 298, 299; car, I., 286.
TRESTLE:
Cascade, California, III., 144.
Lucin cut-off, III., 137, 140, 141.
Papio valley, III., 134.
Trans-Siberian Railway, III., 95.
Uganda Railway, II., 61.
TUBULAR:
Britannia, I., 142, 146, 151, 152.
Victoria (old), I., 206, 208, 211.
VARIOUS:
Cape to Cairo Railway bridges, II., 154.
El Koye, I., 338.
Irlam, Manchester Ship Canal, I., 166.
New Victoria, I., 205.
Rhodesia Railway bridges, II., 161.
Salisbury, II., 53.
Saltash, I., 34, 36–40.
Sittang, Burma, II., 433–437.
Tel-el-Shihab, I., 343.
Uganda Railway bridges, II., 61.
Vadi Ptil, Hedjaz Railway, I., 349.
Volga, III., 82.
Warburton, Manchester Ship Canal, I., 166.
White's Creek, Canadian Pacific Railway, I. 278.
Britannia Tower, I., 150.
Broken Hill, Cape to Cairo Railway, II., 160.
Brooke sounder, II., 279.
Brunel, Isambard Kingdom, I., 35.
Brunel, Marc Isambard, I., 182.
Buoys for submarine cable, *see* "Cables, Buoys."

C

CABLES, SUBMARINE:
CONDUCTORS AND COMPLETE CABLES:
First Atlantic cable deep-sea type, II., 285.
First Atlantic cable shore-end, II., 285.
1865 Atlantic cable main type, II., 365.
1866 Atlantic cable shore-end, II., 368.
Types of electrical conductors, III., 357.
Typical Atlantic cable core, III., 359.
Modern Atlantic cable types, III., 361.
MANUFACTURE:
Putting sheathing on cable, II., 284.
Coiling cable in factory tanks, II., 286.
Stranding machine, III., 358.
Gutta-percha covering machine, III., 358.
SURVEYING, ETC.:
Brooke sounder for obtaining samples of the ocean bed, II., 279.
CABLE ABOARD SHIP:
Coiling cable in hold of *Great Eastern*, II., 367.
Cable coiled in *Great Eastern*, III., 366.
PAYING-OUT MACHINERY, ETC.:
Principle of self-releasing brake, II., 291.
Principle of Bright's paying-out gear II., 292.
Bright's paying-out gear on *Agamemnon*, II., 294.
Drum and brake, III., 367.
Fleeting knives, III., 367.
Modern dynamometer gear, III., 368.
Bright's holding-back gear, III., 368.
Friction table on *Dacia*, III., 368.
General arrangement of paying-out gear on *Great Eastern*, III., 366.
Picking-up machine used for recovering the 1865 Atlantic cable, II., 369.
Under-running first Atlantic cable off Valencia, II., 290.
Diagram to explain how 1865 cable was brought up, II., 372.
Great Eastern picking up the 1865 cable, II., 373.
BUOYS:
Balloon buoys, III., 371.
Buoys, grapnels, etc., used on 1866 expedition, II., 369.
End of cable buoyed, III., 369.
Unshackling a buoy, III., 370.
LANDING CABLE:
Hauling cable ashore by steam, III., 371.
Landing Irish end of the first Atlantic cable at Valencia, II., 288.
Landing American end of the first Atlantic cable in Trinity Bay, II., 361.
Silvertown landing shore-end, III., 372.
SPLICING:
Preparations for slipping splice out from stern, III., 372.
Slipping bight at bows, III., 373.
Preparing to let go final splice, III., 374.
Letting go final bight, III., 374.
STATIONS, TESTING APPARATUS, ETC.:
Commercial Company's station at Waterville, III., 376.
Reflecting galvanometer, II., 293.
Small testing hut, III., 370.
Stations in Newfoundland, primitive, II., 278, 362.
Testing room on *Colonia*, III., 375.
TELEGRAPH SHIPS:
Colonia, III., 363.
Faraday, III., 363.
Iris, III., 364.
Silvertown, III., 365.
Telconia, III., 364.
Cable-laying ships: *see* above.
Cableways:
Beachy Head, I., 382, 383.
Famatina (in Andes), I., 120, 125, 126, 127.
Various systems explained, I., 128.
Zambesi Bridge, I., 96.
Caissons:
Dock gate, II., 186.
Double deck for Hudson River tubes, II., 112.
Forth Bridge, I., 326, 328.
Pennsylvania Railroad tunnel shafts, II., 116.
Rotherhithe Tunnel, I., 53, 54.
St. Louis Bridge, II., 165.
Thames Tunnel shaft, I., 184.
Victoria Bridge piers, I., 207.
"Camels" for ship salvage work, I., 43.
CANALS:
IRRIGATION:
Bari Doab, III., 240.
Ganges, III., 239, 241, 242.
Gunnison, II., 96.
Okanogan, II., 86.
Salt River, II., 100.
Shoshone, II., 101.
Sirhind, III., 238.
Truckee Carson, II., 91, 92.
Yellowstone, II., 91.
NAVIGATION:
Manchester Ship, I., 152–171.
Panama, II., 129–149.
Suez, I., 241–256.
Cantilevers:
Blackwell's Island, II., 272, 273, 274.
Forth Bridge, I., 332, 333, 335, 336.
Grand Trunk Railway Arch Bridge, III., 281, 282.

Niagara Falls and Clifton Bridge, III., 285.
Zambesi Bridge, I., 97, 98.
Car dumper at work, III., 259.
Carnac, " Lines " of, I., 8, 9.
Cars, racing motor:
De Dion, 1894, III., 322.
Levassor, 1895, III., 323.
Bollée, 1898, III., 324.
Panhard, 1899, III., 325.
Napier, 1902, III., 327.
Mercedes, 1903, III., 328.
Darracq, 1904, III., 328.
Darracq, 1905, III., 330.
Thomas, 1905, III., 330.
Napier, 1905, III., 331.
Darracq, 1905, III., 331.
Clément-Bayard, 1908, III., 332.
Weigel, 1908, III., 332.
De Dietrich, 1908, III., 332.
Mercedes, 1908, III., 333.
Napier, 1908, III., 333.
Mercedes, 1909, III., 333.
Church car on Trans-Siberian Railway, III., 87.
Clearing sand from Trans-Caspian Railway, II., 376.
Cleopatra's Needle, II., 22–27.
Coal tip at Partington, I., 168.
Collision with a whale while cable-laying, II., 358.
Colorado River closure, III., 113–121.
Colossal planer, II., 382, 383, 384.
Colossi at Thebes, I., 10, 12.
Comic sketch of Fell Railway, III., 305.
Conning tower, I., 446.
Conversion of gauge of Great Western Railway, I., 108, 112, 113, 114, 115.
Cranes:
Floating, lifting boiler, II., 80.
Goliath, III., 66, 69, 78.
Titan, I., 178; III., 67, 68, 77.
Sheer-legs, lifting test load, II., 67.
Culebra cut, Panama Canal:
Views of, II., 143.
Sections, II., 144, 145.
Ladder dredger at work in, II., 146.
Curve in tunnel, I., 60; II., 123.

D

DAMS:
Bhatghur, III., 243.
Blackwater (Kinlochleven), III., 274.
Caban Coch, III., 188.
Careg Ddu, III., 185.
Craig Goch, III., 182.
Colorado River, III., 118, 120, 121.
Cross River, III., 102, 103, 104.
Croton, New, III., 96, 97, 100, 101.
Ganges Canal, temporary, III., 239.
Gatun, II., 142.
La Grange, II., 93.
Marikanave, III., 245, 247.
Minidoka, II., 86.
Needle dams, III., 173–176.
Olive Bridge, III., 105, 106.
Pen-y-Gareg, III., 190.
Roosevelt, II., 99.
Truckee, II., 92.
Twin Falls, II., 94.
Vischer's Ferry, III., 166.
Vyrnwy, III., 178.
Delta barrage, II., 390.
Desert, Arabian, I., 342.
Divers, naval, I., 441; diver descending into water at Winchester Cathedral, III., 314; on artesian well work, III., 343.
DOCKS:
Canada dry dock, Liverpool, II., 174.
Dry dock, section of, II., 178.
Entrance to, II., 186.
Liverpool, II., 176.
Manchester, II., 185.
Southampton new wet dock, II., 173, 181, 182.
Tilbury, II., 176.
Trafalgar, II., 179.
Wall of dock, II., 184.
DOCKS, FLOATING:
Barcelona depositing, II., 410.
Bermuda, docking central portion, II., 414.
Depositing dock, principle of, II., 412.
Flensburg off-shore, II., 415.
Genoa, outrigger, II., 411.
Off-shore, II., 413.
Outrigger, II., 413.
Stettin, *Spree* lifted, II., 417.
Trinidad, II., 409, 416.
Two-walled, types of, II., 413.
Dolmen, I., 6.
" Dotter," for gun practice, I., 413.
DREDGERS:
Bucket, I., 248, 249; II., 133, 136.
Long-shoot, I., 170, 248.
Suction, I., 254; II., 133, 136; III., 163, 167, 169.
Drills, power:
At La Obispo, Panama Canal, II., 139.
Brandt, III., 153, 159.
Drilling machine, multiple, II., 67.
Dynamometer car, railway, II., 253–255.

E

EARTHQUAKE, effect on buildings, II., 10, 11, 13.
Elevators, grain—at Fort William, I., 284; at St. John's, New Brunswick, III., 297.
Embankments:
Ashokan reservoir, III., 106.
Ellesmere Port, I., 161.
Ince Bay, I., 162.
Pool Hall Bay, I., 159.
Lucin cut-off, III., 138.
Omaha cut-off, III., 134.
Engines, marine:
Charlotte Dundas', II., 30.
Deutschland's, II., 29.
Empress Queen's, paddle, II., 35.
Mauretania's, II., 40.
Quadruple expansion, II., 34.
Scene in engine-room of battleship, I., 445.
Ermack, III., 123.
Excavators:
Lubecker, II., 180, 182; III., 168, 169.
Thompson ladder, I., 301.

F

FACSIMILE of one of the first messages sent over the first Atlantic cable, II., 363.
Fell centre-rail track, III., 302; radial tank engine, III., 302; railway, comic sketch of, III., 305.
Ferrying locomotive across Kafué River, II., 159.
Field anvils, Roman and English compared, I., 19.
Filter beds, III., 207.
Fire at Baku, II., 324.
Fire control on battleship, I., 448.
Fishguard harbour—old, I., 173; new, 173, 180.
Flag, Italian, presented to Mr. J. B. Fell, III., 304.
Floating centre spans of Sittang Bridge, II., 435.
" Freezing out," I., 67.
Funnels of *Mauretania*, II., 42.
Furnace chargers, mechanical:
For pig iron, III., 269.
For slabs, III., 270.

G

GALVANOMETER, reflecting, II., 293.
Gap, the, in the Rockies, I., 272.
Gas cleaners, I., 220, 221.
Gas engines:
Clerk double-acting, I., 217.
Körting 600 horse-power, I., 215.
Two-cycle, I., 223.
Five 2,000 horse-power, I., 224.
Nürnberg 900 horse-power, I., 218.
1,800 horse-power, I., 222.
2,400 horse-power, I., 222.
Oechelhauser, I., 223.
Otto cycle, principle of, I., 216.
Premier 2,000 horse-power, I., 219.
Gas producer, I., 218.
Gauge arch, I., 64.
Giant of Kerdef, I., 7.
Glaciers at Eismeer station, III., 310.
Gladiator, H.M.S., I., 41–48.
Gradients on London Tube Railways, I., 310.
" Great Divide," the, I., 276.
Great Eastern, I., 317; II., 366, 371, 373, 374.
Grouting apparatus, I., 309.
Guns, 12-inch:
Breech action, I., 405.
Firing, I., 448.
In trial barbette, I., 410.
Lifting on deck, I., 404.
Number of rounds fired per minute, I., 409.
Penetration, I., 408.
Range, I., 407.
Shells, I., 411.
Wire-winding, I., 406.
Gushing or spouting oil-wells, II., 330, 331, 332.

H

HAIFA, landing constructional material for Hedjaz Railway at, I., 341.
HARBOURS:
Dover:
Block-making yard, III., 70.
Divers, III., 66, 78.
Diving-bell, III., 71.
Lowering concrete block, III., 73.
Plan, III., 79.
West end of island breakwater, III., 72.
Fishguard, I., 172, 173.
Vera Cruz, III., 75, 76, 77.
Hauling stone bull, I., 14.
Hawkshaw, Sir John, I., 82.
Hydraulic weir shutters, III., 235; wheel piers, II., 252.

I

INCLINE, Kikuyu escarpment, II., 58, 59, 60.
Inspection car, petrol driven, for railways, II., 157.
Irrigation:
Basin and perennial, diagram showing principle, II., 387.
Irrigation works:
In India, III., 232–249.
In United States, II., 81–102.

J

JETTY at head of Loch Leven, III., 272.
Jhelum weir, III., 232.

K

KAFUÉ River, ferrying locomotive across, II., 159.
Kinlochleven aluminium works, III., 272–277.

L

LANDING American end of first Atlantic cable, II., 361.
Launching ways, II., 75, 76, 78.
Levels of Colorado River, III., 121.
LIGHTHOUSES:
Beachy Head, I., 383, 384.
Bell Rock, I., 373.
Bishop Rock, iron, I., 378.
Stone, I., 378–381.
Chicken Rock, I., 376.
Dhu Heartach, I., 373.
Eddystone:
New, I., 376.
Rudyerd's, I., 371.
Smeaton's, I., 371, 373.
Winstanley's, I., 371.
Fastnet, I., 374, 375.
Skerryvore, I., 373.
Wolf, I., 376.
LOCKS:
Barton, I., 160.
Eastham, I., 158.
Gatun, II., 139.
Irlam, I., 153.
Poe, III., 171, 172.
Waterford, New York, III., 166.
Weitzel, III., 171, 172.
LOCOMOTIVES, STEAM, II., 193–215; *see* Subject Index.
LOCOMOTIVES, ELECTRIC, II., 217–222; *see* Subject Index.
Lubecker excavator, II., 180, 182; III., 168, 169.

M

MAFEKING, II., 162.
Magnet, electric:
Lifting pig-iron, III., 262.
Lifting plate and three men, III., 262.
Lifting "skull cracker," III., 263.
MAPS:
AQUEDUCTS, ETC.:
Ashokan reservoir, III., 104.
Birmingham aqueduct, III., 189.
Catskill aqueduct, III., 107.
Croton, old and new aqueducts, III., 98.
Liverpool aqueduct, III., 180.
Manchester aqueduct, III., 187.
CANALS:
Manchester Ship, I., 155, 171.
Panama, II., 130, 131, 134, 141.
Suez, I., 243.
RAILWAYS:
Bergen-Kristiania, III., 348.
Canadian Pacific, I., 259.
Cape to Cairo, II., 153.
Fell, III., 303.
Florida East Coast Extension, I., 137.
Hedjaz, I., 340.
Jungfrau, III., 307.
Trans-Caspian and Orenburg, II., 377.
Trans-Siberian, III., 85.
Tube railways of London, I., 228.
Uganda, II., 51.
White Pass, I., 22.
TUNNELS:
Alpine, III., 152.
New York, II., 104.
New York Subway, II., 343.
Rotherhithe, I., 51.
Thames, I., 183.
VARIOUS:
African Trans-continental Telegraph route, I., 198.
Atlantic cables, projected routes for, II., 281.
Baikal, route of transport of parts, I., 78.
Barur tank system in Madras, III., 244.
Chenab River and Canal, III., 236.
Colorado River closure operations, III., 115.
Godaveri delta, III., 244.
Indian rainfall, III., 233.
Indian rivers and chief irrigation works, III., 234.
Kinlochleven aluminium works, etc., III., 273.
London drainage system, III., 210; Barking outfall works, III., 214.
London water supply, III., 197.
London to Ireland main routes, I., 179.
Niagara Falls, II., 296.
Nile valley, II., 386.
United States—arid, semi-arid, and humid regions, II., 88; natural forests and irrigation projects, II., 88.
Victoria Falls, I., 92.
Marconi towers, Poldhu, II., 438–444.
Marine engines, *see* "Engines, Marine," and "Turbines, Steam."
Menai Suspension Bridge, I., 144, 145.
Menhir, I., 7.
Metacentre, I., 352.
Milwaukee, III., 125, 126, 127.
Model of ship, wax:
Cutting, I., 350.
Completed, I., 351.
Testing, in tank at Washington, I., 357, 358.
Mombasa, landing railway material at, II., 59.
Monolith, concrete, sinking a, for dock wall foundations, II., 183.
Montauk Theatre, moving the, II., 445, 446.
Mont Cenis Road, III., 303.
Mosque at Tebuk, I., 348.
Mould loft, II., 69.
Monument:
Hedjaz Railway at Haifa, I., 339.
Lesseps, at Port Said, I., 256.
Moving buildings bodily, II., 445, 447.

N

NATALA, II., 389.
New River, at Hoe Lane pumping station, III., 196.
New York Subway, II., 342–354.
Niagara Falls, II., 295, 296, 297, 311.
Niagara, U.S.N.S., II., 287, 360.
Nile, statue of Father, II., 385.
Nile valley, perspective view and map, II., 386.

O

OIL tank steamer, Swan principle, II., 339.
Oil wells:
Baku, II., 330, 331, 333.
California, II., 335.
Texas, III., 332.
Open-hearth steel furnaces:
Diagram of, III., 265.
Row of, III., 266.
Tapping, III., 267.
Tilting type, III., 268.
Ore handling plant:
Automatic unloader, III., 258, 259.
Hulett conveyor, III., 257.

P

PANIC in Severn Tunnel, I., 86.
Paying-out gear, Bright's, II., 292–294.
Pelton wheel, III., 276.
Petroleum wells, II., 321–341.
Philæ, temple of, II., 406.
Picking-up machine for submarine cables, II., 369.
Pier of Victoria Bridge, I., 207–209.
Pile-driving—through ice, I., 280; San Francisco Bay, III., 146.
Pipe joint, "muff," III., 276.
Pipe line:
Birmingham aqueduct, III., 186.
Kinlochleven, III., 275.
Planing machine, II., 382, 383, 384.
PORTRAITS:
Brett, John Watkin, II., 280.
Bright, Sir Charles T., II., 280.
Brunel, Isambard Kingdom, I., 35.
Brunel, Marc Isambard, I., 182.
Bythell, J. K., I., 157.
Eads, James B., II., 163.
Field, Cyrus West, II., 280.
Gibson, Herbert M., I., 157.
Hawkshaw, Sir John, I., 82.
Hunter, W. H., I., 157.
Latimer, E., I., 157.
Lesseps, Ferdinand de, I., 242.
Myddleton, Sir Hugh, III., 195.
Stephenson, Robert, I., 147.
Telford, Thomas, I., 143.
Van Horne, Sir William, I., 259.
Walker, T. A., I., 83.
Williams, Sir Edward Leader, I., 156.
POWER STATIONS:
Canadian Niagara Falls Power Company, II., 304, 305, 306.
Kinlochleven, III., 277.
Lot's Road, Chelsea, III., 228.
New York Metropolitan, II., 16.
New York Subway, II., 353.
Niagara Falls Hydraulic and Manufacturing Company, II., 298, 299.
Niagara Falls Power Company, II., 300, 301, 302.
Ontario Power Company, II., 306, 307, 308, 309.
Power transmission lines, II., 309.
Propellers, aerial, III., 42, 43.
Pumping stations:
Abbey mills, III., 213.
London waterworks, III., 198.
Lot's Road, III., 218.
Pyramids of Egypt, I., 12, 13; Great Pyramid and *Mauretania*, I., 319.

Q

QUAY at Fishguard harbour, laying first block, I., 178.

R

RAFTS colliding with Victoria Bridge piers, I., 214.
RAILWAYS:
Barmen-Elberfeld, II., 124–128.
Bergen-Kristiania, III., 347–356.
Canadian Pacific, I., 262, 264, 265, 267, 268, 269, 271, 272, 276, 277, 278, 279, 280, 283, 284, 285.

Cape to Cairo, II., 150–162.
Central Pacific, III., 142, 143, 144, 147.
Chicago Freight Subways, I., 359–367.
Florida East Coast Extension, I., 130–141.
London tubes, I., 230–240, 300–311.
St. Gothard, III., 148.
Trans-Caspian, II., 376, 378, 380.
Trans-Siberian, III., 81–95.
Uganda, II., 50–64.
Union Pacific, III., 130, 132, 134, 136, 137–141.
Wetterhorn Electric, II., 188–192.
White Pass, I., 21–33.
Range, maximum, of big guns, I., 407.
REINFORCED CONCRETE:
Adhesion of steel and concrete, II., 425.
Aqueduct, III., 274.
Ballroom, II., 432.
Beam, II., 423, 424, 426.
Bridges:
Blagodatuoie, II., 429.
Chingford reservoir, III., 204.
Hudson Memorial, II., 276.
Sambre, II., 419.
Cattle gallery, Fishguard harbour, I., 179.
Columns, II., 426, 427.
Cost, compared with steel, II., 421, 422.
New General Post Office buildings, II., 430.
Pebbles for, II., 420.
Piles, II., 428.
Sand for, II., 420.
Staircase, II., 430.
Strength, compared with steel, II., 421.
Torpedo station, II., 432.
Viaducts, I., 135–139, 141.
Water tower, II., 431.
RESERVOIRS:
Ashokan, III., 104.
Chingford, new, III., 200–203.
Honor Oak, III., 193, 205.
Lake Fife, III., 243.
Lake Vyrnwy, III., 178.
Lake Whiting, III., 243.
Marikanave, III., 248.
Ring of lining, Rotherhithe Tunnel, I., 55.
Riveters, hydraulic, II., 73, 74, 252.
Rolling mill for armour plate, I., 398.
Roosevelt, President, at Panama Canal works, II., 149.
Rotary digger, Price's, I., 302, 303, 305.
Rudder frame of battleship, I., 391.

S

SADDLE, cable, Runcorn transporter bridge, I., 298; Brooklyn Bridge, II., 261.
Sailing ships:
Great Harry, I., 314.
Santa Maria, I., 313.
Royal George, I., 314.
Sakieh, II., 389.
Saloon, dining-car, Rhodesian railways, II., 150.
Salt Lake valley, compared with valley of the Jordan, II., 85.
Salton Sea, sunset on, III., 114.
Sand panels for keeping sand off railway, II., 380.
Sand washer, mechanical, III., 207.
Screw, Roman, I., 20.
Searchlights at work, I., 449.
Sewers of London:
Bermondsey, III., 220.
Catford-Blackheath, III., 225.
Diversion chamber, III., 215.
Northern outfall, III., 216, 218, 222.
Plumstead-Crossness, III., 209, 223.
Weir chamber, Abbey Mills, III., 215.
Shadoof, II., 389.
Sheer-legs, in Suez Canal, I., 253, lifting 180 tons, II., 67.
Shells for big guns:
Group of 12-inch, I., 412.
Number fired per minute (comparative diagram), I., 409.
Penetration (comparative diagram), I., 408.
Weight of 12-inch, I., 411.
SHIPBUILDING:
Adriatic on slips, II., 66.
Bending plate in hydraulic press, II., 72.
Cranks turning in lathe, II., 69.
Drilling armour plates, II., 74.
Frames, stringers, etc., II., 70.
Launching cradle, II., 75, 76.
Launch of *Nelson*, II., 77; of *Lord Nelson*, II., 78.
Mauretania being framed, II., 72.
Mauretania's keel and double bottom, II., 71.
Mould loft, II., 69.
Multiple drilling machine, II., 67.
Riveter, hydraulic, II., 74; portable, II., 73.
Shaft tunnel of big liner, II., 79.
Sheer-legs, II., 67.
Stern frame, II., 73.
Shipbuilding feats, extraordinary:
Ermack, with new bow fitted, III., 123.
Mabel Grace, with bows shattered, III., 128.
Milwaukee, in dock after accident, III., 125; ready for new bow, 126; old and new parts ready for fitting, 127.
Wittekind in dock for lengthening, III., 122.
SIGNALLING, RAILWAY:
AUDIBLE:
Cab indicator, whistle, and bell, II., 239.
General view of cab, showing apparatus installed, II., 240.
Rear part of locomotive, showing contact shoe, II., 239.
Ramp for operating audible signal, II., 239.
AUTOMATIC ELECTRIC:
Automatic brake application, II., 236.
Diagram showing operation of electric railway, II., 235.
Diagram showing operation of steam railway, II., 237.
On New York subway, II., 351.
On single lines:
Diagram showing operations of successive sections, II., 238.
Electric staff holder, II., 237.
Principle of automatic signalling, II., 234.
Signal on American railways, II., 236.
Signal on North-Eastern Railway, II., 235.
INTERLOCKING:
Facing point lock, II., 228.
Lever locking, II., 229.
System of interlocking points and signals, II., 228.
Tappets, etc., of locking frame, II., 229.
POWER SIGNALLING:
Electric locking frame, New York Central Railway, II., 230.
Electric locking frame at Reading, Great Western Railway, II., 231.
Electro pneumatic signals, Washington, II., 234.
Point-shifting electric motor, II., 232.
Pneumatic switch, II., 233.
Signal box at Earl's Court, II., 238.
SEMAPHORES, ETC.:
Balanced arm, II., 227.
Disc signals, old, II., 226.
Distant signal, II., 226.
Gantry, Crewe, II., 225.
Stepped signals, II., 226.
Sludge being transferred to vessel at Barking, III., 217.
Sluices between Manchester Ship Canal and Mersey, I., 160.
Sluices, Stoney, II., 398.
Snow ploughs, railway:
Bergen-Kristiania Railway, III., 350, 354.
Canadian Pacific Railway, I., 263.
Rotary, II., 242–245; III., 350, 354.
Wedge shaped, II., 242.
Snow-sheds:
Bergen-Kristiania Railway, III., 352, 353.
Canadian Pacific Railway, I., 280, 281.
Sphinx, I., 15.
Spike, driving the last of the Canadian Pacific Railway, I., 283.
Spreader, mechanical dump, II., 146.
Stations, railway:
Bogotol, Trans-Siberian Railway, III., 91.
Doppersberg, Barmen-Elberfeld Railway, II., 125, 126.
Eigergletscher and Eigerwand, Jungfrau Railway, III., 309, 301.
Hallingskeid, Bergen-Kristiania Railway, III., 347.
Moazamma, Hedjaz Railway, I., 347.
Moose Jaw, Canadian Pacific Railway, I., 262.
New York Subway, II., 354.
Tebuk, Hedjaz Railway, I., 347.
Vancouver, Canadian Pacific Railway, I., 286.
Statue of Liberty, III., 250–256.
STEAMSHIPS (*see* "Warships," "Cables, Submarine, Telegraph Ships"):
Angara, I., 77, 78.
Baikal, I., 65–78.
CARGO:
Cantilever framed, I., 355.
Clermont, *Comet*, and *Charlotte Dundas*, I., 315.
Development in horse-power (1840–1907), I., 320.
Development in size, I., 318.
Doxford "turret," I., 354.
Great Eastern, *see* Index.
Half section, I., 353
Longitudinal framed, I., 355.
Longitudinal section, I., 354, 355.
Lusitania, I., 312; II., 172.
Mauretania, I., 319.
Oil tanker, longitudinal section, II., 339
Tank, half section, I., 356.
Steam shovel, II., 138:
In new dock, Southampton, II., 181, 182.
On Canadian Pacific Railway, I., 268.
STEEL-FRAME BUILDINGS:
Brooklyn Academy, II., 16.
Buffalo Savings Bank, II., 17.
Crystal Palace, II., 3.

Earthquake, effects on, II., 10, 11, 13.
Foundations, caissons for, II., 7.
Ritz Hotel, II., 6, 8.
Singer building, II., 5.
Height, increase in, II., 3.
Metropolis Bank bu lding, II., 9.
Metropolitan Life Assurance building, II., 15, 20.
Metropolitan power station, II., 16.
Montgomery Ward building, II., 21.
Protection of steel work against fire, II., 12, 13.
Singer building, II., 18, 19.
Speed of construction, II., 5, 10.
Truss carrying twelve stories, II., 16.
Wind-bracing, II., 14, 15.
Stone carriers, Indian, III., 247.
Stonehenge, I., 6, 14.
Strathcona, Lord, driving last spike of Canadian Pacific Railway, I., 283.
Superheater, Schmidt's, II., 256.
Surveying on Mount Leone, for Simplon Tunnel, III., 154.

T

TANK steamer for oil carriage, II., 339.
Telegraph line construction — African Trans-continental Telegraph:
Bracketing wire, I., 193.
Erecting pole, I., 199.
Repairing station, Nkata, I., 202.
Straining wire, I., 200.
Telegraph station:
Kota Kota, I., 203.
Newfoundland, II., 278, 362.
Poldhu, II., 438, 439.
Waterville, III., 376.
Teredo, ravages of, I., 180.
Thermal efficiencies of engines, I., 226.
Thames Tunnel, *see* "Tunnels."
Thompson ladder excavator for tunnelling, I., 301.
Timbering in tunnel, I., 88.
Time-table of Trans-Caspian Railway, II., 381.
Toggle, adjusting, for cantilevers of arch bridge, III., 278, 285.
Tombs, Nebatean, I., 348.
Torpedoes:
Dropping gear, I., 439.
Firing, I., 436, 438.
Instruction, I., 440.
Picking up, I., 433.
Ready for discharge, I., 435.
Section of Whitehead, I., 434.
Whitehead in tube, I., 434.
Towers of Forth Bridge, I., 329, 330.
Track thrower, mechanical, II., 147.
Traction engine on Uganda Railway works, II., 57.
Train—Canadian Pacific Railway advertisement, I., 285; contractors' electric, for tunnel, I., 237.
Trestles at Colorado River closure, III., 113; *see* "Bridges."
Truss, timber, New York Subway, II., 347, 348.
Tubes—Britannia Bridge, I., 148, 149; Victoria Bridge, I., 211, 213.
TUNNELLING:
Chicago Subway, moulding, I., 363, 364.
Cut-and-cover, I., 52.
Exploring below tunnel with boring machine, II., 120.
Lining with brickwork, I., 88.
Lining with iron, I., 55, 62.
Pilot tunnel, II., 109.
Rock boring, II., 118; III., 159.
Rust joints, I., 62.
Screw pile foundation, Pennsylvania Railroad, II., 113.
Setting out, I., 231, 232.
Shaft sinking, I., 53, 54, 81.
Surveying, II., 105, 106.
TUNNELLING SHIELDS:
Assisted shield method, I., 305.
East River gas tunnel shield, II., 107.
Greathead shield, I., 233, 238, 304.
Hooded shield, I., 306, 308.
Hudson River Tunnel shield, II., 108, 109.
Lower Hudson River Tunnel shield, II., 110.
Pennsylvania Railroad East River Tunnel shield, II., 114, 115.
Rotherhithe Tunnel shield, I., 57, 58, 59.
Station shields, I., 233, 238, 240.
Steering shield round curve, I., 234; vertically, 236.
Thames Tunnel shield, I., 186, 187.
Turbines, steam, Parson's:
Blading, II., 38.
Drum, II., 39.
Lot's Road power station turbine, III., 231.
Mauretania's, II., 40.
Principle of, II., 37.
Rotor complete, II., 39.
Turbines, water:
Niagara Falls Power Company's, II., 302, 303.
Ontario Power Company's, II., 308.
Pelton wheel, III., 276, 277.
TUNNELS:
Central London Railway station, I., 230.
City and South London (section), I., 229.
Gunnison, II., 96.
Huntley irrigation, II., 86.
Jungfrau Railway, III., 305, 308.
Mink, Canadian Pacific Railway, I., 262.
Myrdal, Bergen-Kristiania Railway, III., 351.
New York:
Battery, II., 121.
East River gas, II., 107.
Harlem River, II., 104.
Lower Hudson River, II., 110.
Steinway, II., 121, 122.
Subway, II., 344, 347, 349, 350.
Rotherhithe, I., 49–64.
St. Gothard, entrances, III., 150.
Severn, I., 80, 81, 89.
Simplon:
Brandt drill at work, III., 159.
Brieg portal, III., 161.
False arches, III., 157, 158.
Inroads of water, III., 156.
Iselle portal, III., 160.
Thames, I., 181–192.
Trans-Siberian Railway, III., 81.
Tube of London, I., 311.
Waterloo and City, I., 229.

U

UNDERPINNING:
New York Elevated Railway, II., 350.
New York *Times* building, II., 349.
St. Mary Woolnoth Church, III., 317, 318, 319.
Winchester Cathedral, III., 313.
Unloader, Lidgerwood, II., 142.

V

VALVE gears:
Joy, II., 251.
Stephenson, II., 245.
Walschaert, II., 256.
Viaducts:
Lethbridge, Canadian Pacific Railway, I., 257.
Long Key, I., 139, 141.
Victoria Falls, I., 90, 91, 92 (map), 93 (perspective view), 99.
Vulkan, III., 124.
Vyrnwy, Lake:
Site before flooding, III., 178.
Water impounded, III., 178.
Water tower, III., 181.

W

WALKER, T. A., I., 83.
WARSHIPS:
BATTLESHIPS:
Dreadnought, I., 387, 388; II., 175.
King Edward VII., I., 389.
CRUISERS:
Indomitable, I., 392, 394.
Clearing decks, I., 443, 444.
Conning tower, I., 446.
Engine room, I., 445.
SUBMARINES:
B1, conning tower, etc., I., 429.
B4, cruising, I., 429.
Flotilla at Gosport, I., 426.
Karp awash, I., 427.
Launch of a submarine, I., 432.
Sectional view of, I., 428.
TORPEDO CRAFT:
Dragonfly, II., 43.
Nembo, sections of, I., 419.
Speed and power, I., 421.
Suggested French, I., 417.
Tartar, I., 420.
Viper, I., 424.
WARSHIPS OF THE FUTURE, I., 453–455.
Water cisterns on Trans-Caspian Railway, II., 378.
Water mains, at Staines, III., 199; 40-inch, 208.
Weir, waste, of Lake Fife, III., 237; shutters, hydraulic, 235.
Well-sinking (*see* "Artesian Wells"):
Baku oil wells, II., 326–329.
Roumanian dug wells, II., 325.
Winchester Cathedral, III., 312; underpinning, 313.
Winnipeg, Canadian Pacific Railway sidings at, I., 284.
Wireless telegraphy—cabin on warship, I., 450; station at Poldhu, II., 438, 439.

THE END